BANGLADESH DELTA PLAN 2100

Baseline Studies: Volume 1

Water Resources Management

Editors
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General Economics Division
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Baseline Studies on
Water Resources Management

Volume 1

Baseline Study 1: Sixty Years of Water Resources Development in Bangladesh: Lessons Learnt
Baseline Study 2: River System Management
Baseline Study 3: Water Resources
Baseline Study 4: Groundwater
Baseline Study 5: Coast and Polder Issues
Baseline Study 6: Water Supply and Sanitation
Baseline Study 7: Part A- Sediment Management;
Part B- Meghna Estuary Study

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A H M Mustafa Kamal, FCA, MP
Minister
Ministry of Planning
Government of the People's Republic of Bangladesh

Message

I am happy to know that the General Economics Division (GED) of Bangladesh Planning Commission is publishing the Baseline Studies in six (6) volumes which were prepared for formulation of the Bangladesh Delta Plan (BDP) 2100.

Over the past 47 years since independence Bangladesh has secured tremendous gains in development. Bangladesh has achieved food self-sufficiency and the economy is gradually transforming from an agrarian base towards a modern manufacturing and services economy. Making this growth sustainable is even more challenging in the face of extreme adverse climate variability, with frequent storm and tidal surges, flooding, and droughts. I am confident that the BDP 2100 will amply guide us in realizing the vision that is aspired in the plan of being a prosperous country beyond 2041 and also contribute directly in making the growth sustainable by ensuring long term water and food security, economic growth and environmental sustainability while effectively reducing vulnerability to natural disasters and building resilience to climate change and other delta challenges. I hope BDP 2100 will also contribute to the making of 5 year plans as well as contribute to achieving SDG's and other national policy goals.

The Baseline Studies generated both quantitative and qualitative benchmark information for relevant subject areas of the plan and identified critical areas for future intervention. It also forms the basis for determining strategies and measures that have been suggested in BDP 2100 for different climatic Hotspots.

I am particularly pleased to note that BDP 2100 being a techno-economic plan, is the first attempt in our national planning history to formulate a real long term plan prepared by GED. The publication of the Baseline Studies in book form which served as basis for the preparation of the BDP 2100 has immense importance to keep the institutional memory preserved. These will be useful references to the policymakers, development partners, academics, researchers, students and professionals alike to further research endeavor and knowledge sharing.

In this instance, I would congratulate relevant officials of GED of Bangladesh Planning Commission for their hard work in compiling the Baseline Studies in book form. My sincere appreciation goes to the experts in their respective fields for completing the Background Studies for formulation of the BDP 2100.

(A H M Mustafa Kamal, FCA, MP)

M. A. Mannan, MP
State Minister
Ministry of Finance and Ministry of Planning
Government of the People's Republic of Bangladesh

Message

It gives me immense pleasure to learn that the General Economics Division (GED) of Bangladesh Planning Commission is going to publish 26 Baseline Studies in six (6) volumes which have been used as the inputs for preparing the country's first long term Plan i.e. Bangladesh Delta Plan (BDP) 2100. The Baseline Studies of BDP 2100 are the culmination of both quantitative and qualitative benchmark information for relevant subject areas of the plan and identified critical areas for future intervention. I believe, GED of Bangladesh Planning Commission has pursued with various eminent professionals, scientists, researchers, academia etc. at national and international levels for conducting these Baseline studies.

I know that BDP 2100 is the long term plan for the country to realize sustainable and a commonly agreed upon strategy with specific short, medium and long term interventions involving all relevant stakeholders for an optimum level of water safety and food security as well as sustained economic growth of Bangladesh and a framework for its implementation.

I congratulate the GED for taking up this bold initiative. I would like to thank the authors and also the reviewers who have contributed to prepare these Baseline Studies. Documented Baseline Studies will also be helpful for policy planners, development practitioners, researchers, academicians, professionals and even students as well. I also expect that the Baseline Studies will be useful for the officials of GED to prepare necessary policy briefs and write-ups they often prepare. I believe that not only GED but also other relevant officials will be immensely benefited with these Baseline Studies for upgrading and updating their knowledge and professional competences. Finally, I thank GED leadership for undertaking this endeavor for publishing Baseline Studies of the BDP 2100 for much wider use.

I wish all the best and all out success.

(M. A. Mannan, MP)

Shamsul Alam
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Prefatory Comments

Bangladesh is one of the largest deltas of the world and its rivers and floodplains support life, livelihood and economy. The country is defined by the delta, with almost a third of the country lying less than 5 (five) metres above sea level, on the contrary however, coastal zone, the low-lying area, is highly vulnerable, especially to cyclones and storm surges. In addition, salt-water intrusion, floods, sea level rise intensify the vulnerability of the community of the areas. These problems are likely to become even worse due to climate change adverse impact.

Many more challenges lie ahead for Bangladesh, the most important being pressure on land use, environmental protection, governance, globalization and macro-economic development. Given the ambition to be a developed country by 2041, addressing the expected impacts of climate change, there is a need for an integrated approach to future land and water management in relation to water safety, agricultural growth and food security. The recent and future anthropogenic changes in the hydrological cycle due to e.g. climate change, construction of dams and barrages in the upstream countries in combination with increasing water demand are expected to make future water governance and management even more challenging.

With a view to meeting the above challenges, the Government of Bangladesh (GoB) requested the Government of the Netherlands (GoN) to assist for formulation of adaptive, multi-sectoral, comprehensive and holistic Delta Plan taking lessons from Dutch experiences. The GoN agreed to provide the necessary support through its Embassy in Dhaka. In accordance with the decision of the Government, the General Economic Division (GED) of the Planning Commission, Ministry of Planning was assigned to lead the formulation of Bangladesh Delta Plan 2100, as the GED is mandated for medium and long term planning at the national level.

Bangladesh Delta Plan 2100 has been conceived as a techno-economic, long-term, holistic, water centric, strategic plan. As such, formulation of strategies in the short (budgeting), medium and long term is the most significant part in the planning process. The long term strategies will help to fulfil the Delta Vision, whereas the short and medium term strategies will help achieve benefits within the country’s 5 year planning horizon as well as contribute to achieving SDG’s and other national policy goals. An interactive planning process has been followed comprising three major steps: i) Conducting Baseline Studies; ii) Formulation of Adaptive strategies; and iii) Development of the Delta Management Framework. These steps were supported by country wide consultation processes which eventually led to the outcome of an Investment and Implementation Plan.

The project has prepared 26 Baseline Studies on known delta problems, reviewing existing policies and governance challenges in the sector of water resources, land, environment, disaster, agriculture, fisheries, livestock, transportation, finance, governance, knowledge generation etc. The studies followed the basic steps of reviewing the current policy situation, assessing the status of individual sectors, identification of drivers or pressures, conducting integrated analysis for the right interpretation of problems, challenges and knowledge gaps. For starting an integrated analysis with stakeholders it was essential to create an overview of already established and agreed-upon policies as well as to rank priorities for further investigation, research and discussion. The key elements in the approach were (a) knowing the present state, problems, impacts, challenges and current responses or interventions; (b) consideration of uncertainties of social and natural systems and knowledge gaps; (c) the evaluation of drivers, trends or events in the interaction between the delta and society.

These Baseline Reports have been clustered into Six Volumes on the basis of thematic issues and topics.

Volume 1: Water Resources Management consists of seven Baseline Reports: 1. Sixty Years of Water Resources Development in Bangladesh: Lessons Learnt; 2. River System Management; 3. Water Resources; 4. Groundwater;

5. Coast and Polder Issues; 6. Water Supply and Sanitation; 7. Part A- Sediment Management and Part B- Meghna Estuary Study;

Volume 2: Disaster and Environmental Management consists of four Baseline Reports: 8. Climate Change; 9. Disaster Management; 10. Environmental Pollution; 11. Ecological Setting;

Volume 3: Land Use and Infrastructure Development consist of three Baseline Reports: 12. Land Resources Management; 13. Urbanization and Settlement; 14. Sustainable Transportation and Infrastructure;

Volume 4: Agriculture, Food Security and Nutrition consists of four Baseline Reports: 15. Agriculture and Food Security; 16. Fisheries; 17. Livestock; 18. Forests and Biodiversity;

Volume 5: Socio-Economic Aspects of the Bangladesh Delta consist of three Baseline Reports: 19. Population Growth and Management; 20. Socio-Economic and Demographic Condition; 21. Socio-Economic Characteristics of Chittagong Hill Tracts;

Volume 6: Governance and Institutional Development consists of five Baseline Reports: 22. Institutional Framework and Arrangements; 23. Information and Knowledge Management; 24. Regional Cooperation; 25. Financial Mechanisms & Arrangements in the Water Sector in Bangladesh; and 26. Private Sector Engagement in Deltas.

Volume 1: What's there in Water Resources Management

Sixty Years of Water Resources Development in Bangladesh – Lessons Learnt: Bangladesh is a rapidly developing country, which envisages becoming a developed country by 2041. Bangladesh Delta Plan 2100 is expected to play a crucial role in achieving that goal, especially in terms of water resources management and climate change. Bangladesh Water Development Board (BWDB), being a principal public sector agency, has played a vital role in the development of water resources of the country. WARPO was established much later as an apex body to take care of water resources planning concerns. The main objective of this Baseline Study is to learn lessons from the water resources development that took place in Bangladesh during the last sixty years. The main focus is given to the role of BWDB in water resources development, and that of WARPO in Water Resources planning, as well as contributions by BADC, LGED and other water related agencies in brief.

BWDB has implemented nearly eight hundred projects during the last sixty years, providing flood management facilities to 6.3 million ha land and irrigation facilities to 1.6 million ha land. These projects provide flood-free land for agriculture, enhanced the degree of safety to human lives, livestock, settlement, industry and infrastructure, help increasing cropping intensity, higher crop yields, facilitate culture fisheries and controlled hazards due to floods and surges. The FCD/I projects, besides flood protection, also provide multiple services i.e. embankments are used as national, regional and rural roads; slopes are used for plantation; in some cases embankments are used as flood shelter; borrow pits are used for fish culture. However, in some cases, FCD/I interventions have reduced the area of culture fisheries, restricted the free navigation routes and created water logging.

The institutional development and the capacity building of the two principal water resources institutions, BWDB and WARPO, need immediate attention. WARPO could not play its expected role as a national water resources planning institution, because of its inadequate institutional capacity and lacking in the right kind of expertise. On the other hand, the BWDB has weakened considerably by unplanned staff reduction without proper exercises; the long-term as well as project level planning capacity of the institution reduced drastically. The argument was that WARPO would fill up the planning vacuum which didn't happen. The two organisations should be revamped to enhance their capability to plan or implement any large water resources project according to their respective mandate.

River System Management: The Ganges-Brahmaputra-Meghna river system is one of the largest river systems in the world, delivering one trillion cubic meter of water and one billion tons of sediment to the Bay of Bengal annually. Subsequently, the huge sediment supply makes the system highly dynamic. The frequent shifting of the rivers resulting in river bank erosion is a major cause of poverty in the country. About 6000 ha lands are lost each year due to erosion. Therefore, the stabilization of river courses and reclamation of land from the active corridor of the rivers are very important. At present, the river stabilization facilities cover only about 10% of the total length of the river courses. The popular demand is to maintain river courses through the river bank stabilization and dredging.

Water Resources: Bangladesh is a country richly endowed with water resources, but 80% of the local rainfall and the inflows of 57 trans-boundary rivers are concentrated into a five months' wet season from June to October. In this period rainfall is more than twice the potential evapotranspiration, but in the remaining seven months, only one-third. These twin problems cannot be considered in isolation. The future of the people, flora and fauna of Bangladesh depends on these two problems being managed jointly, in an integrated manner. As such, water resources management and flood risk management are the main concerns to be addressed in BDP 2100.

Coast and Polder Issues: Bangladesh coast is one of the most dynamic areas in the country, and covers an area of approximately 32% (47,201 km^2) area of the country, comprising 19 districts. The vast inflows of sediment from the Ganges-Brahmaputra-Meghna river system are subject to coastal dynamic processes generated by tides, waves and currents that lead to erosion and accretion/land reclamation potentials. The tidal amplitude ranges from approximately 1.5 m in the west to over 4 m in the east (6 m at spring tide near Sandwip). In the western part one of the world's largest mangrove forests, the Sundarbans, is situated. The coast provides many natural resources, such as fertile lands and fish but the living conditions are trending arduous due to freshwater limitations, salinity intrusion and frequent cyclonic storms which can create huge surges of up to 9 m height. The Coastal Embankment Project (CEP) in the 1960-1970 has been the largest physical intervention so far in the coastal zone of Bangladesh. While the 1.2 million hectares under agriculture or aquaculture is sufficient testament to the benefits of this project, there have been unintended environmental consequences that have become increasingly problematic in the last three decades in certain parts of the coastal zone.

Water supply and sanitation: Water supply and sanitation remains high on the Government's priority list as indicated by GoB's concern with SDG6. Especially with respect to sanitation, substantial parts of the population suffer inadequate provisions. During flooding the situation worsens dramatically with large number of people lacking minimum facilities for water supply and sanitation. Both in suffering from 'delta effects' (flooding, dropping groundwater tables, salinity and water pollution) and in contributing to delta effects (sewerage polluting surface water, water supply resulting in over exploitation of groundwater) the WATSAN domain is very much relevant to the Bangladesh Delta Plan 2100. Growing pace of urbanization is putting pressure on the already stressed water supply and sanitation systems.

Sediment Management: A large quantity of sediments are carried annually by the Brahmaputra, the Ganges and the Meghna rivers. By analysing available data, it appears that the total sediment load in the Brahmaputra-Jamuna and the Padma system has increased during the period from 1960s to 1990s, while bed material load (coarse sediment) has decreased more than 50%. Sediment balance within the river system indicates an aggrading system in 1960s, while it turned into degrading system in the 1990s. During the reducing phase of coarse sediment, river responded by widening and lowering its riverbed. The rate of river bank erosion and widening was very high in the Jamuna and the Padma rivers. It is likely that in near future, supply of sediment would reduce, on the contrary, demand of coarse sediment will increase. Increasing of temperature due to climate change may cause increased rainfall and increased sediment yield. Unplanned mining of coarse sediment is rapidly diminishing the sediment storage, which would not be replenished anymore. On the contrary, demand of coarse sediment will be increased. Imposing levy on sediment mining may reduce the extraction and planned extraction could reduce the river bank erosion and suffering of the population living on the natural levees.

Meghna Estuary Study: The Ganges-Brahmaputra-Meghna (GBM) river system is carrying huge volumes of sediment to the Bay of Bengal through several estuaries; among them the Meghna Estuary is the largest. Estuaries are the place where sweet water mixes with saline water. The sediment particles drop here to form land. The Ganges-Brahmaputra-Meghna (GBM) system carries sediment mainly during monsoon and deposits in the Meghna Estuary and tides redeposit the sediment during the dry season. As a result, the Passur and Baleshwar rivers form their estuaries in the west coast of Bangladesh. Due to a lack of fresh water flow from the Ganges and Padma rivers, these estuaries have less sediment from the riverine source, rather they receive some sediment from east of the coast. The abundance of sediment in the Meghna Estuary gives Bangladesh an opportunity to reclaim lands within the vicinity of Bangladesh territory in the Bay of Bengal. In the past, some interventions were made in the estuaries for reclaiming land. In the purpose of Coastal Zone strategy formulation and Investment Plan preparation, this study would be supportive for Bangladesh Delta Plan 2100.

(Shamsul Alam)

Acknowledgements

The Bangladesh Delta Plan 2100 has been prepared by the General Economics Division (GED) of the Bangladesh Planning Commission and is supported by the Government of the Netherlands. At the behest of the Hon'ble Prime Minister of the People's Republic of Bangladesh, Sheikh Hasina, a Memorandum of Understanding (MoU) was signed between Bangladesh and the Netherlands to cooperate on Bangladesh Delta Plan 2100. During a meeting in The Hague, Prime Minister Sheikh Hasina of the People's Republic of Bangladesh and Prime Minister Mark Rutte of the Netherlands renewed their support to the preparation and implementation of Bangladesh Delta Plan 2100.

Hon'ble Minister Mr. AHM Mustafa Kamal, M.P., Ministry of Planning, always encouraged the formulation of the project and contributed to the formulation of the plan passionately. Mr. Abdul Mannan, M.P., State Minister, Ministry of Planning and Ministry of Finance, gave valuable time and guidance.

We acknowledge the guidance and timely direction provided by the National Steering Committee (NSC) headed by Mr. Md Abul Kalam Azad, Principal Secretary of the Hon'ble Prime Minister and Dr. Kamal Abdul Naser Chowdhury, Principal Secretary of the Hon'ble Prime Minister and Mr. Md. Nojibur Rahman, Principal Secretary of the Hon'ble Prime Minister in consecutive terms for their contributions to successful completion of the Plan.

We are also grateful to the valuable contribution of the Panel of Experts headed by Dr Jamilur Reza Choudhury for their review of the Plan contents, and the important suggestions to improve those. The reviewers' contribution to the Baseline Reports are also acknowledged for their valuable comments and suggestions for improvement.

The International Economics Wing of the General Economics Division (GED), Bangladesh Planning Commission, coordinated all the reports under the broad and extensive guidance of Dr. Shamsul Alam, Member (Senior Secretary), GED, so that, the Plan could meet the quality standard. Mr. Naquib Bin Mahbub, Division Chief; Mr. Md. Mafidul Islam, Joint Chief; Dr. Md. Mizanur Rahman, Ex. Project Director; Mr. Mohd. Enamul Haque, Deputy Chief and Project Director, Dr. Md. Taibur Rahman, Senior Assistant Chief; Mr. Md. Murtuza Zulkar Nain Noman, Senior Assistant Chief, Mr. Mohammad Asaduzzaman Sarker, Senior Assistant Chief and Mirza Md. Mohiuddin, Assistant Chief provided constant support in the process of preparation of the plan.

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We from GED gratefully acknowledge the efforts by all concerned.

June 2018

BDP 2100 Baseline Studies

Volume 1

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Abbreviations

ADB	Asian Development Bank
ADG	Additional Director General
ADPC	Asian Disaster Preparedness Centre
AIT	Asian Institute of Technology
Aman	Main Monsoon Paddy
AR5	Fifth Assessment Report of IPCC
As-	Arsenic
ASI	Above sea level
ASLR	Accelerated Sea Level Rise
Aus	Late dry season/ early monsoon Paddy
B. Aman	Broadcast Aman
BADC	Bangladesh Agricultural Development Corporation
Baor	Ox-bow lake
BARC	Bangladesh Agricultural Research Council
BBS	Bangladesh Bureau of Statistics
BCM	Billion Cubic Metres
BDP	Bangladesh Delta Plan
BDT	Bangladesh Taka
BHWDB	Bangladesh Haor and Wetland Development Board
BIP	Barind Irrigation Project
BIWTA	Bangladesh Inland Water Transport Authority
BMDA	Bangladesh Multipurpose Development Authority
BOD	Biochemical Oxygen Demand
Boro	Winter (dry) Season Paddy
BPDB	Bangladesh Power Development Board
BRAC	Bangladesh Rural Advancement Committee
BRB	Brahmaputra Right Bank
BSCIC	Bangladesh Small and Cottage Industries Corporation
BTM	Bangladesh Transverse Mercator
BUET	Bangladesh University of Engineering Technology
BWDB	Bangladesh Water Development Board
CBO	Community Based Organization
CCP	Chittagong Coastal Plain
CDMP	Comprehensive Disaster Management Plan
CDS	Coastal Development Strategy
CDSP	Char Development and Resettlement Project
CEGIS	Center for Environmental and Geographic Information Services
CEIP	Coastal Embankment Improvement programme
CEP	Coastal Embankment Project
CERM	Chief Engineer River Management
CERP II	Coastal Embankment Rehabilitation Project-II
CETP	Central Effluent Treatment Plan

CFCD	Coastal Flood Control and Drainage
CGIAR	Consultative Group on International Agricultural research
CHT	Chittagong Hill Tracts
COD	Chemical Oxygen Demand
CPP	Cyclone preparedness programme
CPWF	Challenge Program on Water and Food
CSIRO	Commonwealth Scientific and Industrial Research Organization, Australia
CWU	Consumptive Water Use
CZ	Coastal Zone
CZPo	Coastal Zone Policy
DAP	Detailed Area Plan
DDM	Department of Disaster Management
DEM	Digital Elevation Model
DG	Director General
DMA	District Metered Area
DMC	Design Management Consultancy
DO	Dissolved Oxygen
DoE	Department of Environment
DoF	Department of Fisheries
DPHE	Department of Public Health Engineering
DPP	Development Project Proforma
DPs	Development Partners
(D)SMA	(Dhaka) Statistical Metropolitan Area
DSP	Deep Set Pump
DTW	Deep Tube Well
ECNEC	Executive Committee of the National Economic Council
ECNWRC	Executive Committee of the National Water Resources Council
ECRRP	Emergency Cyclone Recovery and Restoration Project
EDP	Estuary Development Program
EIA	Environmental Impact Assessment
EPADC	East Pakistan Agricultural Development Corporation
EPIWTA	East Pakistan Inland Water Transport Authority
EPWAPDA	East Pakistan Water and Power Development Authority
EQS	Environmental Quality Standards
ETP	Effluent Treatment Plants
FAO	Food and Agriculture Organization (of the United Nations)
FAP	Flood Action Plan
FC	Flood Control
FCD	Flood Control and Drainage
FCD	Flood Control and Gravity Drainage
FCDI	Flood Control, Drainage and Irrigation
FFWC	Flood Forecasting and Warning Centre
FPCO	Flood Plan Coordination Organization
FY	Financial Year
GBM	Ganges, Brahmaputra and Meghna

GDA	Ganges Depended Area
GDP	Gross Domestic Product
GDP	Gross Domestic Product (GDP)
GED	General Economics Division
GIS	Geographical Information System
GK	Ganges Kobad-ak
GoB	Government of Bangladesh
GoN	Government of Netherlands
GPWM	Guidelines for Participatory Water Management
GPWM	Guidelines for Participatory Water Management
GTPE	Ganges Tidal Plain East
GTPW	Ganges Tidal Plain West
GW	Ground water
HBT	Health Based Target
HtR	Hard to Reach
HTW	Hand Tube Well
HYV	High Yielding Variety
IBRD	International Bank for Reconstruction and Development
ICDDR,B	International Centre for Diarrhoeal Disease Research, Bangladesh
ICZM	Integrated Coastal Zone Management
ID	Institutional development
IEC	Information, Education and Communication
IFAD	International Fund for Agricultural Development
IFC	International Finance Corporation
IPCC	Intergovernmental Panel on Climate Change
IPM	Integrated Pest Management
IPSWAM	Integrated Planning for Sustainable Water Management
IPSWAM	Integrated Planning for Sustainable Water Management
IRLP	Indian River Linking Project
IUCN	International Union for the Conservation of Nature
IUCN	International Union for the Conservation of Nature
IWM	Institute of Water Modelling
IWT	Inland Water Transport
JDLNA	Joint Damage, Loss and Needs Assessment
JMC	Joint Management Committee
MP	Joint Monitoring Programme
JRC	Joint Rivers Commission
JRC	Joint Rivers Commission
Kharif	Summer, monsoon cropping season
KJDRP	Khulna-Jessore Drainage Rehabilitation Project
LB	Left Bank
LGD	Local Government Division
LGD	Local Government Division
LGEB	Local Government Engineering Bureau
LGED	Local Government Engineering Department

LGI	Local Government Institution
LGI	Local Government Institute
LIC	Low Income Community
LLP	Low Lift Pump
LLP	Low Lift Pump
LRP	Land Reclamation Project
M&E	Monitoring and Evaluation
MASP	Multi-Annual Strategic Plan
MDG	Millennium Development Goal
MDP	Meghna Deltaic Plain
MES	Meghna Estuary Study
MGC	Mongla-Ghasiakhali Channel
MLD	Million Litre per Day
mm	Millimeter
MoA	Ministry of Agriculture
MoHFW	Ministry of Health and Family Welfare
MoLGRD&C	Ministry of Local Government and Rural Development & Co-Operatives
MoPHE	Ministry of Public Administration
MoS	Ministry of Shipping
MOU	Memorandum of Understanding
MoWR	Ministry of Water Resources
MPO	Master Planning Organization
msl	Mean Sea Level
MTR	Mid Term Review
NAP	National Agriculture Policy
NARS	National Agricultural Research System
NEC	National Economic Council
NEMAP	National Environmental Management Action Plan
NEPo	National Environmental Policy
NFiPo	National Fisheries Policy
NGI	Norwegian Geotechnical Institute
NGO	Non-government organization
NGOs	Non-Governmental Organizations
NLUPo	National Land Use Policy
NRLP	National River Linking Project
NRW	Non Revenue Water
NSAPR	National Strategy for Accelerated Poverty Reduction
NSAPR	National Strategy for Accelerated Poverty Reduction
NSDS	National Sustainable Development Strategy
NTU	Nephelometric Turbidity Unit
NWMP	National Water Management Plan
NWMP	National Water Management Plan
NWMP	National Water Management Plan
NWP	National Water Plan
NWPo	National Water Policy

NWRC	National Water Resource Council
NWRC	National Water Resources Council
NWRD	National Water Resources Database
O&M	Operation and Maintenance
ODS	Ozone-Depleting Substances
PCBs	Polychlorinated Biphenyls
PIP	Priority Investment Projects
PIRDP	Pabna Irrigation and Rural Development Project
PPP	Public Private Partnership
PRIO	Peace Research Institute Oslo
PSF	Pond Sand Filters
PSU	Policy Support Unit
PWD	Public Works Department
PWSS	Pourashavas Water Supply Sections
R&D	Research & Development
Rabi	Winter (dry) season crop
RCP	Representative Pathways
RDCD	Rural Development and Cooperatives Division
RHD	Roads and Highways Department
RMSLR	Relative Mean Sea Level Rise
SAARC	South Asian Association for Regional Cooperation
SACOSAN	South Asian Conference on Sanitation
SAIRLP	Strategic Analysis of India's River Linking Project
SBRI	Ship Breaking and Recycling Industry
SDP	Sector Development Plan
SFYP	Sixth Five Year Plan
SIA	Social Impact Assessment
SLR	Sea Level Rise
SMA	Statistical Metropolitan Areas
SSSU	Survey & Study Support Unit
SST	Shallow Shrouded Tubewell
STP	Sewage Treatment Plants
STW	Shallow Tubewell
SUA	Survey Unit Anwesha
SW	Surface Water
SWR	South-Western Region
SWTP	Surface Water Treatment Plant
T. Aman	Transplanted Aman
Tcf	Trillion Cubic Feet
TDS	Total Dissolve Solid
TFR	Total Fertility Rate
TRM	Tidal River Management
TS	Thematic studies
UfW	Unaccounted for Water
UN	United Nations

UNDP	United Nations Development Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNICEF	United Nations Children's Fund
VEI	Vitens Evides International
VSST	Very Shallow Shrouded Tubewell
WAP	Water Allocation Plan
WAPDA	Water and Power Development Authority
WARPO	Water resource Planning Organization
WASA	Water and Sewerage Authority
WB	World Bank
WFP	World Food Programme
WHO	World Health Organization
WMA	Water Management Association
WMCA	Water Management Cooperative Association
WMF	Water Management Federation
WMG	Water Management Group
WOP	Water Operators Partnership
WSP	Water Safety Plan
WSS	Water Supply and Sanitation
WTP	Water Treatment Plant
WW	Water Works
WWTP	Waste Water Treatment Plant

Glossary

Definition of Seasons: In this report, the seasons are defined as follows:

Season	Calendar Period
Pre-monsoon	April and May
Monsoon	June through September
Post-Monsoon	October and November
Dry	December through March

Distribution of various Land Types

Land Type	Description	Flooding characteristics
F_0	Highland	Above normal flood level
F_1	Medium Highland	Flooded up to 90 cm
F_2	Medium Lowland	Flooded between 90 cm and 180 cm
F_3	Lowland	Flooded between 180 and 300 cm
F_4	Very Lowland	Flooded deeper than 300 cm

BASELINE STUDY: 01

Sixty Years of Water Resources Development In Bangladesh : Lessons Learnt

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Executive Summary: Study 01

Most of the thematic areas under the Bangladesh Delta Plan 2100 (BDP 2100) are related to water. Hence, it is important to gather knowledge on the development of the water resources sector in last 60 years. Bangladesh, as a riverine country, faces major inter-related delta challenges in water and food security as well as in socio-economic development. It also experiences too much water during the monsoon and too less water in the dry season. The available water resources comprise of internally generated surface water through rainfall-runoff and trans-boundary inflows as well as the groundwater, another source of water supply. The main water resources management issues are flood, drought, cyclone & storm surge, salinity intrusion, water logging, riverbank erosion and sea level rise. Over a period, these issues have been exacerbating due to anthropogenic (human) interventions, which contribute to the deterioration of the water quality of the country.

In the context of Bangladesh, water sector is a prime sector, as it witnessed huge development over the years and decades since the ending of the British Colonial Rule. To cater the need of the country in the field of irrigation and power, a special organization titled EPWAPDA was created in mid-1950s'. Later, it divided into two wings, the water wing titled as Bangladesh Water Development Board (BWDB). Gradually, more water related organizations like BADC, LGED, DPHE, WASA, etc. came into functional with specific issues. However, BWDB remained the prime organization in the field of water resources development and management.

BWDB has implemented nearly eight hundred projects during the last sixty years, providing flood management facilities to 6.3 million ha land and irrigation facilities to 1.6 million ha land in the country. Other mentionable activities are the development of drainage canal facilities (4425 km), town protection facilities (22 nos), bridge/culvert construction (5643 nos), land reclamation (1020 km^2), and construction of embankments (11,393 km) etc. The BWDB activities contributed to achieving water and food securities through the development of flood control and irrigation projects. These projects provide flood-free land for agriculture, enhanced degree of safety to human lives, livestock, settlement, industry and infrastructures, multiplicity of cropping intensity, higher crop yields, culture fisheries and controlled hazards due to floods and surges.

Out of several successful irrigation projects, the Ganges-Kobadak (GK) and Teesta Barrage Projects are noteworthy. The GK Project plan has provided supplementary irrigation during the Aus and Aman crop seasons, implemented in six phases, covering the areas up to Jessore. However, the only two phases implemented and the remaining four phases are not yet done. So far, the irrigation coverage of the Teesta Barrage Project, is 0.15 million ha out of a planned irrigation area of 0.75 mil ha, which is yet to get the supplementary irrigation facilities. The Teesta Barrage Project is a showpiece project, which was planned, designed and implemented using local expertise and funding from the national budget, which demonstrates that barrages over major rivers could be developed by similar initiatives.

The barrages over the Manu, Buri Teesta and Tangon River distribute irrigation water through gravity flows. Their performance show that similar barrages are feasible to construct over the rivers like Dudhkumar, Dharla, Sonai-Bardal, Jury, Khowai, and Gumti. The implementation of a small dam in Mohamayachara Irrigation Project proves that the feasibility of such type of small reservoirs in suitable locations of Chittagong, Cox's Bazar, Bandarban, Khagrachari, Rangamati, Sylhet and Moulvibazar districts can be useful. Similarly, in the coastal region, there is a possibility of developing freshwater reservoirs for irrigation purposes like the ones developed in the Muhuri, Matamuhuri, Bakakhali and Idgaon rivers in past years.

The analysis of size-wise coverage by the major river management facilities, the number of very large projects dominates, which constitute about 79%, followed by large projects 14%; the rest 7% by medium and small projects of the total area. The embankments for the FCD/I projects are normally designed for 25 years return-period of floods; only the embankments on the major rivers are designed for 50 years return period of floods and the sea-facing embankments for 100 years return-period of storm surges. The FCD/I systems, besides flood protection, also provide multiple services i.e. embankments are used as national, regional and rural roads; slopes are used for plantation; in some cases, embankments are used as flood shelter; borrow pits are used for fish culture etc. Nevertheless, in some cases, FCD/I interventions have reduced the area of culture fisheries, restricted the free navigation routes and created water logging in a number of areas.

From the previous experiences, it is evident, that the task of bank protection is highly challenging in terms of planning, design, execution as well as operation & maintenance (O&M). The bank revetment, groynes or spurs constructed in small and medium rivers are functioning satisfactorily. However, the performance of hard points, bank revetments, groynes or spurs constructed in large rivers like the Brahmaputra/Jamuna, the Ganges, the Padma and the Meghna has been relatively poor, compared to the small rivers, with maintenance and repair costs often substantially exceeding initial capital costs. The closing anabranch of the Jamuna in Sirajganj shows that such type of closing of anabranches and thereby flow diversion is possible in the major rivers provided with sufficiently strong crossbars, however, the partial dredging in the rivers will not sustain as a long-term solution to bank erosion in the rivers. In such case, construction of crossbars and bank protective works in combination with intelligent/adaptive dredging in well-planned manner would give better result.

Participatory Water Management forms an integral part of water resources development, which was not realised until many water development projects malfunctioned or failed to meet local people's aspiration. The peoples' participation concept would not work smoothly unless there is a good understanding and coordination between the implementing agencies and the local communities. Some water resources projects, especially the donor-aided projects took the peoples' participation as one of its main components, as well as in Early Implementation Project (EIP) and Delta Development Project (DDP), funded by the Netherlands and Land Reclamation Project (LRP) during 1970s and 1980s. For EIP, the initial contribution of the Netherlands Government was to support relatively small labour-intensive, quick yielding water sector projects through BWDB. Water Management Improvement Project (WMIP), South-West Area Integrated Water Resources Planning and Management Project (SWAIWRPMP), Integrated Planning for Sustainable Water Management (IPSWAM) are some of the other projects where participatory water management followed intensely.

The development of a reliable Flood Forecasting and Warning System (FFWC wing, BWDB) since 1972 has become an important non-structural measure for flood hazard. Though at present, the flood forecasts are for 5-days, it needs extension to longer time forecasts to be used by farmers and fishermen. The daily flood forecasts disseminate through print and electronic media. However, this information is not readily comprehensible by the communities of the affected areas. Hence, the dissemination of information at the community level needs to be further developed.

Huge amount of money was invested over the last sixty years to provide a reasonable safety level to the citizens from natural disasters like floods, droughts, storm surges, salinity intrusion, river erosion etc. An enabling environment has been generated for growing high yielding crops both in monsoon as well as in the dry season, for culture fisheries including shrimps, building industries, houses and other social infrastructure in floodplains.

Any sort of development activities in a floodplain will definitely affect the natural environment and bio-diversity. When the development of water resources started in 1950, the population was approximately 35 million, suffering from chronic food shortage, especially in the coastal and drought prone regions. Now, the country grows enough food to feed 165 million people. The water sector has contributed substantially to come to this level of food production.

The task of providing a higher level of safety from natural disasters requires a significant level of investment in upgrading water infrastructure to meet the impacts of climate change in the form of increased flooding, droughts and sea level rise. Moreover, rapid urbanization and industrialization in flood prone areas also demand high levels of safety measures to protect the investments. In the 1950s and 1960s, floods used to damage only crops and houses, but at present, the scenario is different. Any extreme flood will stop the economy from moving for several days, even for several weeks and result in huge losses to infrastructure. One of the examples of the above statement is the Dhaka International airport, which was closed down for several days during the 1988 floods.

Over the years, BWDB has developed a large number of infrastructure across the country. These infrastructures need regular and adequate operation and maintenance to keep them in top operating condition. The earthen embankments are subject of erosion by wind and rainfall, human intervention as well as animal grazing. The drainage channels undergo annual silting up during monsoons and floods, requiring maintenance excavation every year. The sluice gates corrode due to salinity and other reasons. It is evident that a substantial amount of money is required every year for proper operation & maintenance. Unfortunately, BWDB gets only about 10 percent of its requirement for this purpose. As a result, most of the maintenance works suffer severally due to lack of money. Consequently, the infrastructure deteriorates to such an extent, demanding rehabilitation at huge cost.

The institutional development and the capacity building of the two principal water resources institutions, one for planning WARPO and another for implementation BWDB, need immediate attention. WARPO could not play its expected role as a national ware resources planning institution, because of inherent weakness in its institutional formation and lacking in right sort of expertise. On the other hand, the BWDB has weakened considerably by unplanned staff reduction. The long-term as well project level planning capacity of the institution reduced drastically without proper exercises. The argument was that WARPO would fill up the planning vacuum, which WARPO also failed to do. This led one to think whether the organization is capable to plan and implement any large water resources project as per its mandate. In its earlier days of BWDB (1972), a good bunch of talented engineers formed the core group of planning and design directorates of BWDB. However, that capability degraded over the years and at present, even a small project is outsourced to knowledge institutes like IWM or CEGIS. The other reason of deterioration is that many experienced and qualified engineers have retired and the new intake got little or no training to carry out their assignments with their own capacities.

In order to move forward, the country has to ensure reasonably high level of safety from the natural disasters to protect lives, properties and on-going huge investments. Moreover, the conservation of water resources is also of prime importance to meet the growing demands of industrialization and urbanization. As Bangladesh aspires to become a middle-income country by 2021 and developed country by 2041, the water resources sector also need to play a vital role in the nation building.

1. Introduction

The Bangladesh Delta Plan is a water centric multi-sectoral techno-economic long term plan. The Royal Kingdom of the Netherlands has provided assistance through its Embassy of the Kingdom of the Netherlands (EKN) in Dhaka for the formulation of the Bangladesh Delta Plan 2100 (BDP2100). It builds on the Memorandum of Understanding (MoU) between the two countries signed on May 2012 and the preparatory work in 2011-2012 of the Delta Plan Preparatory Team. The decision was made by the Government of the People's Republic of Bangladesh to host the project at the General Economic Division (GED) of the Planning Commission, Ministry of Planning, as the GED is mandated for holistic long term planning at the national level.

The complexity and dynamics of the Bangladesh delta necessitates a plan that can be adaptive to changes. BDP 2100 is a long-term, robust and holistic plan for sustainable development of the Bangladesh delta. It is a long-term techno-economic plan, considering goals for the next one hundred years. The plan is holistic, as it is considering many themes and sectors and bringing together individual strategies. Moreover, the plan is integrated and robust, as it is considering the needs of all water-related sectors in a single platform. The formulation of the BDP 2100 draws on experiences from the Delta Plan formulation process in the Netherlands, while at the same time adapting to the specific needs of Bangladesh and finding inspiration in Bangladesh's long tradition of resilience in adversity and water management.

The country faces major inter-related delta challenges in water safety and food security and socio-economic development and is prone to natural calamities such as floods, cyclones and droughts. There is already high pressure on the available land and water resources in the delta. In order to meet the challenges posed by anticipated climate change and the ever-increasing demand by multi-sectoral water usage, the formulation of a multi sectoral Delta Plan focusing especially on water resources and climate change has been undertaken. Moreover, Bangladesh is a rapidly developing country, which envisages becoming a developed country by 2050. The BDP 2100 is expected to play a crucial role in achieving that goal, especially in terms of water resources management and climate change. The Bangladesh Water Development Board (BWDB), being a principal public sector agency, has played a vital role in the development of water resources of the country. WARPO was established much later as an apex body to take care of water resources planning issues. This report is mainly an attempt to get an insight into the water resource planning and development by WARPO and BWDB as well as contributions by BADC and LGED in brief.

1.1 Objective

The main objective of this study is to acquire necessary lessons from the water resources development that took place in Bangladesh during the last sixty years. In this report, main focus is given to the role of BWDB in water resources development and that of WARPO in water resources planning. However, the role of BADC and LGED in water resources development is also discussed, as part of the study. Additionally, the GoB has formulated a number of plans in the water sector which has also been discussed and reviewed in this report.

Initially, the report intended to present the water development efforts by BWDB only, but in the context of a much wider Delta Plan, it was decided to include the developments by other organizations relatively. However, reporting all relevant agencies' development efforts is not easy within the stipulated time. As such the report will primarily be BWDB-oriented, but the other agencies are also given briefly.

1.2 Country Setting

Bangladesh is a riverine country and most of the area is a low-lying plain land formed from the alluvial soil deposited by rivers. The physiography of Bangladesh can be divided into four broad categories: (i) the hills, (ii) the terraces, (iii) the floodplains, and (iv) the sea. For millions of years, sediments eroded from the Himalayas have been carried to the basin by the rivers Ganges and Brahmaputra, the two very large rivers which originate in the Himalayas. These sediments have formed the world's largest river delta with an area of about 100,000 km^2 and a sub-aquatic fan extending 3,000 km south into the Bay of Bengal. About 90% of the land area of Bangladesh is formed with recently deposited alluvial and deltaic sediments. The surface topography of the fan within Bangladesh is very subdued. The highest elevation is only 90 m above sea-level in the northwest corner of the country, with 75% of the country lying below 29 m above sea level and 50% below 12.5 m. The remaining 10% of the country is formed by raised blocks of sediments making up the Barind Tract, the Madhupur Tract and the Lalmai Hills. These floodplains are formed through sediments deposition by the Ganges and the Brahmaputra rivers, before being uplifted tectonically.

1.3 Historical Background

The history of water resources management in Bengal (now under the jurisdiction of Bangladesh) dates back to the ancient period. The then rulers introduced "overflow irrigation" system for boosting agriculture. The farmers were involved in the operation and maintenance of the system. These practices continued till the beginning of colonial period during the 18^{th} and 19^{th} centuries. The *Zaminders* (local landlords) attached priority on water management because of agriculture and navigation. Levies were collected from the riverine crafts plying over the watercourse, as per instruction from the rulers, by the *Zaminders* (local landlords) and the same would be used for maintaining the canals and drainage channels.

During the colonial period (1757 to 1947), water management practices experienced a changeover. The *Zaminders* were relieved from the responsibility of water management. The British rulers were traders and sailors and had no idea about agriculture, irrigation or water management. They engaged collectors to collect revenue from the farmers. Both the British and their pet rulers, the *Zaminders*, had the prime objective of earning revenue and not providing services to the people, the traditional process of water management gradually went on decline, and the water infrastructure and systems were not properly maintained. The modern period (1947 onward) of water resources development in the country has seen the emergence of structured institutions under the umbrella of a particular ministry. The characteristics of this period are large investments in the large structural interventions, requiring highly technical starts with the large structural interventions.

After the end of colonial rule (till 1952), the Irrigation Department, headed by a Chief Engineer, was assigned with the responsibility of planning, constructing, operating and maintaining works which would serve the purpose of flood control, irrigation, drainage, improving and maintaining inland waterways for navigation and generation of hydroelectric power. But due to too many responsibilities assigned to one department, it was suggested to create a new government corporation with comprehensive responsibility and authority to deal with all water and power development problems. Consequently, a new organization, East Pakistan Water and Power Development Authority (EPWAPDA) was created in 1959, which was even more justified by extreme flooding of the country for the consecutive years from 1954 to 1956, leading to sever food shortage. The formation of the department was also suggested by the Krug Mission from the USA. EPWAPDA had two wings, the Water Wing and the Power Wing, headed by the Commissioner Water, and the General Manager (Power), respectively, both holding the established. The primary functions of EPADC are: to make suitable arrangements throughout Bangladesh for the production, procurement, transport, storage and distribution of essential agricultural inputs such as seed and fertilizers and providing irrigation facilities through utilization of surface and underground water to the farmers.

After the independence of Bangladesh in 1972, EPWAPDA was divided further into two wings namely, the Bangladesh Water Development Board (BWDB) and the Bangladesh Power Development Board (BPDB). The water wing, BWDB inherits the legacy and liability of water wing of the then EPWAPDA. As per recommendation of IBRD, during the period of 1973-80, small irrigation and FCD/FCDI projects were implemented by both public and private initiatives. In 1975, another water and agriculture related organization, namely, Bangladesh Agricultural Development Corporation (BADC) was created from the erstwhile East Pakistan Agricultural Development Corporation (EPADC). In 2009 the corporation was given more responsibilities such as providing irrigation facilities to the farmer through surface water utilization.

Over the years since independence, more organizations were established at the Government and semi-government level, along with some and other organizations in the form of research institute and Trust agencies. Prominent of them are Joint Rivers Commission (JRC), Master Planning Organization (MPO), later transformed and renamed into Water Resources Planning Organization (WARPO), River Research Institute (RRI), Local Government Engineering Department (LGED), Barendra Multipurpose Development Authority (BMDA), Bangladesh Haor and Wetland Development Board (BHWDB), Institute of Water Modelling (IWM), Center for Environmental and Geographic Information Services (CEGIS), etc.

2. Water Management Issues

The main issues for water resources management are flood, drought, riverbank erosion, salinity intrusion, groundwater (both contamination and depletion), land subsidence, drainage congestion, cyclone & storm surges, etc (Figure 2.1). Over time, some of these issues exacerbated due to anthropogenic interventions and unplanned development activities, which happened due to dearth of coordination among the water resources development agencies. On top of these, climate change including sea level rise and trans-boundary issues only add to the complexity of the problems; unfortunately, the magnitude of these problems is only going to increase over the period in near and future. As such, human interventions should be restricted or limited so that the actions do not augment the problems more than what the nature is already causing. This chapter discusses the management issues briefly.

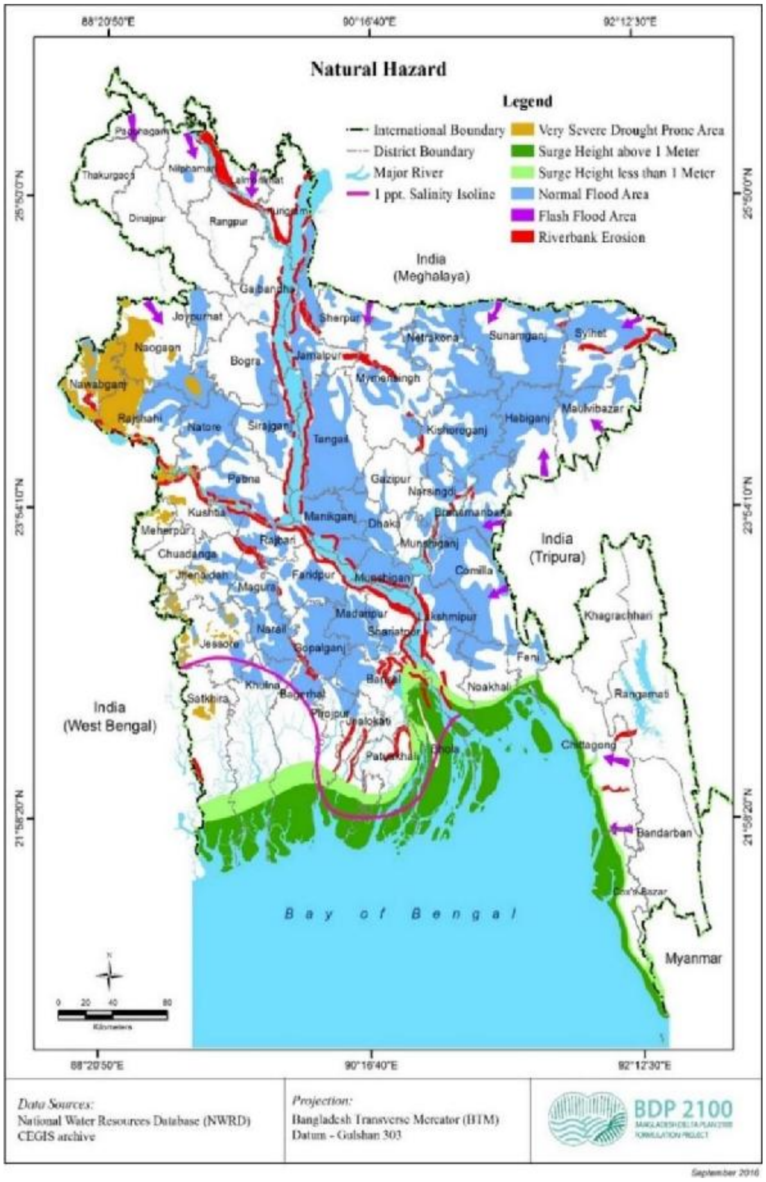


Figure 2.1: Spatial distribution of Water Resources Issues of Bangladesh

Source: BDP 2100

2.1 Flood

Normal flooding in rainy season affects about 22% of the country each year; the land use and settlements are well adapted to it. The most disastrous floods, in terms of lives and livelihoods lost, typically occur in the coastal areas when high tides coincide with the major cyclones (Brammer, 1996). About 1.32 million ha and 5.05 million ha of the total cropped area is severely and moderately flood prone (FAO Aquastat, 2011), making Bangladesh the most flood prone country in the world. Abnormal flooding can submerge about 60% of the land area, damaging crops and property, disrupting economic activities and causing loss of life.

Past Flood Impact Assessments: In order to have a clear understanding about the characteristics of floods and their impact, the floods of 1987, 1988, 1998, 2004 and 2007 analysed and described below.

In 1987, the major parts of Bangladesh received heavy rainfall. Higher concentration of rainfall was recorded during July-September in the northern and north-eastern region. Although the flood peaks in the Brahmaputra and the Ganges occurred at an interval 34 days, the country experienced severe floods and about 39% of the country was inundated, mostly in the north-western region. The Brahmaputra Right Embankment breached at several places.

In 1988, a devastating flood occurred in Bangladesh, inundating 61% area. The flood generated by intensive rainfall that extended over north and northeast Bangladesh, India, Nepal and Bhutan, the most intense local concentrations being in Assam, Meghalaya, and Arunachal Pradesh states of India. The flood peak of the Brahmaputra was the highest, and that of the Ganges was high. Because of the high floods in both Brahmaputra and the Ganges basins and the close synchronization of their peaks with the tidal effect of the Bay of Bengal, resulted in floods of catastrophic scale.

A difference between 1987 and 1988 floods is that in the former, the magnitude of flooding was associated with high rainfall within the country, while in 1988 it was associated with heavy rainfall in the upper catchments outside the country.

During the 1988 floods, the following infrastructure of the BWDB damaged partially or fully as follows:

- Embankments: 1990 km (17.5%)
- Irrigation canals/drainage channels: 283 km (5.3%)
- Structures: 1465 nos (10%)
- Protection works: 265 km (24.8%)

During the 1998 floods, all the flood-producing factors were in a state of adverse combination. However, the most prominent characteristics of the floods were that four flood waves in succession surged through the Brahmaputra, each one coming before the river level could drop down sufficiently to accommodate the next flood. These four flood waves, their peaks, date of occurrence and level above danger level of the Brahmaputra at Bahadurabad are shown in Table 2.1.

Table 2.1: Significant records of 1998 flood on the Brahmaputra at Bahadurabad

Flood Waves	**Peak during 1998 Flood**			**Peak level (m)**	**Above Danger Level (cm)**
	Start	End	Peak		
1st	09 July	19 July	15 July	19.95	45
2nd	19 July	02 August	26 July	20.05	55
3rd	12 August	31 August	20 August	20.17	67
4th	31 August	12 September	08 September	20.37	87

It may be observed that the peaks of the 4 flood waves were increasing and the river at Bahadurabad point was above the danger level for 57 days, and stayed close to the danger level for another 9 days (from 03 to 11 August 1998).

Another important point is that the peak floods of the Ganges at the Hardinge Bridge occurred on 9th and 10th September at a record-breaking level of 15.19 meters, synchronized with the Brahmaputra-Jamuna peak at Aricha. During these floods, the damage to the BWDB infrastructure was as follows:

- Embankments (fully): 252 km (2.2%)
- Embankment (partially): 2738 km (24%)
- Irrigation/drainage canals: 373 km (7.4%)

- Structures: 1031 Nos. (7%)
- Protective works: 187 km (17.5%)

In April 2004, due to heavy rainfall from 11 April in the Meghna basin, flash floods occurred in the north-eastern region causing record damage to Boro crops in Sunamganj, Sylhet and Habiganj. The Surma River at Kanaighat and Sylhet, the Kushiyara River at Amalshid and Sheola, the Manu river at Manu Railway Bridge and the Khowai at Habiganj peaked above danger level for 2 to 10 days.

During the month of July 2004, the Brahmaputra and the Meghna basins experienced 30% and 42% higher rainfall than their monthly normal, whereas the Ganges and the south-eastern hill basins received more or less the same rainfall as their monthly normal. The continuous heavy rainfall over the basins as well as upstream inflows caused flood in the country. Out of 86 water level monitoring points, 35 points crossed the danger level in that month. On the other hand, the situation aggravated further due to the abnormal behaviour of the sea in the second part of July (impact by tidal floods). During the 2004 floods, the following BWDB infrastructure were damaged partially or fully:

- Embankments: 3158 km (27.7%)
- Irrigation canals/drainage channels: 341 km (6.4%)
- Structures: 562 nos. (3.8%)
- Protection works: 178 km (16.6%)

The following experiences were gained from 2004 flood:

- During the flood, the water levels at different locations in the Surma basin exceeded the ever-recorded highest level. Increasing population growth and extensive development in the basin area aggravated flood risk and vulnerability to major losses.
- FCD projects of BWDB functioned properly, except for a breach, which occurred in the Brahmaputra Right Embankment (BRE) at Dhunot, Bogra. These projects could achieve their primary goal of protecting life and property.
- In many places, water started seeping through *ghogs* (holes in embankments), rat holes and holes made by termites in the flood embankments. Nevertheless, BWDB officials and staff with the help of the community people helped in taking corrective measures to repair the embankments on time.
- The railways, highways, roads, etc. constructed across the flood plains, obstructed the drainage of flood flows. The water level differences between upstream and downstream of these structures observed to be very significant. The bridges and openings were ill designed and have inadequate space for unhindered flood flows.

In August 2007, the flood mainly occurred in north-west region and inundated around 42% area of the country. Breaching in the Brahmaputra Right Embankment (BRE) at locations upstream of Sirajganj was the main reason. By 3 August, many highways connecting Dhaka to the rest of the country was impassable and many districts were flood-affected. By 7 August an estimated 7.5 million people had fled their homes. By 13 August, the confirmed death toll was around 405.

2.2 Drought

The number of days without rainfall is expressed as Drought. Droughts occurring in Bangladesh are not meteorological droughts but agricultural droughts, which could be also termed as severe moisture stress.

Occurrences of drought, as a major water deficiency related issue, is most profound in the North-west region (WARPO, 2001), which has the lowest average annual rainfall in the country. The drought situation of the area becomes severe during April-May due to the cumulative effect of presence of soils with low moisture holding capacity (<200 mm available moisture), increasing number of dry days (precipitation <0.5 PET) and occurrence of extreme summer temperature of more than 40°C. The average occurrence of drought in the country is once in 2.5 years; nineteen droughts occurred in Bangladesh between 1960 and 1991.

2.3 Drainage Congestion and Water logging

Water logging is a problem over large parts of the coast, especially in the southwest (Satkhira, Jessore, Khulna and Bagerhat) and south east (Noakhali, Feni) coastal zones. The southwest region is characterized by numerous morphologically active tidal rivers, which are the main drainage networks for coastal polders and low-lying beels. Thus, the natural drainage pattern of the area is predominant by the influence of the incoming tide from the sea. The tidal flow brings huge quantity of silt from the sea into the river systems of the coastal area. The distribution of waterlogged areas of eight selected upazilas under three districts is shown in Table 2.2.

Table 2.2: Major water logged areas in southern region

District Name	Total area of the district (ha)	Total area of the upazila affected (ha)	Water logged area (ha)		
			No of Upazila	Area (ha)	% of total affected upazila
Jessore	260 694	94 911	3	15 700	16.5
Khulna	438 900	51 245	2	19 023	37.1
Satkhira	381 729	96 298	3	33 470	34.8

Source: FAO report, 2015

Before polderisation in early 1960s' and 1970s', major parts of incoming silt deposited naturally on the low-lying depression areas (beels). On the other hand, there was significant amount of fresh water flow from the Ganges, which helped to maintain the perennial tidal rivers in this part of the country. The continued fresh water flows from the Ganges helped to flush the incoming sediment with high tide from the sea and thus, the proper drainage capacity of these tidal creeks maintained naturally. After polderisation and significant reduction of fresh water flows from the Ganges, this natural process seemed hampered significantly. In addition, the reduction of dry season flow in the downstream of the Ganges and its distributaries due to withdrawal of water upstream by operation of Farakka Barrage contributed to increased sedimentation in the riverbeds and tidal creeks. This reduction of fresh water had increased the salinity concentration, which proportionately increased sediment concentration and simultaneously silt deposition in the peripheral rivers during ebb tide.

2.4 Riverbank and Coastal Erosion

The rivers of Bangladesh are very dynamic in nature. Around 6,000 ha of land along the banks of the major rivers (the Ganges, the Jamuna the Padma and the Lower Meghna) are eroded annually, leading to the displacement of about 50,000 people every year. The net erosion and accretion for the period 1973 – 2015 (402 years) is estimated to be about 182,000 ha and 80,000 ha respectively.

The Meghna Estuary is a delta-building estuary, size of which is ever increasing. In this lower deltaic zone, both erosion and deposition are active. Besides, the north part of estuary is eroding. About 40% of Sandwip island in the east was eroded and there were considerable losses in the north of Hatia, north-east of Bhola and the south-west of the former Ramgati island. Beyond the estuary, the rate of coastal changes are small or undetectable. In the south-western coast, there have been local erosion of small amount, with generally increasing westward towards the Hooghly estuary of India. The prevention of erosion in the Meghna estuary is difficult due to its highly dynamic nature. The Lower Meghna River is eroding its left bank along the Ramgati and Kamalnagar Upazila under Laxmipur district and the erosion rate is in the range of 11-27 ha/km/yr over a length of 31 km (IWM, 2013). Bhola Island has been experiencing erosion over a length of 80 km and about 5,640 ha of land was consumed by the river from 2003 to 2014.

2.5 Transboundary Issues

Bangladesh and India share some of the most intricate and complex river systems in the world. The formidable network of waterways includes three major rivers; the Ganges, the Brahmaputra and the Meghna. These three river basins are flood prone and vulnerable for flood consequences. The frequency and intensity of floods is expected to increase in future due to climate change. In the case of Bangladesh, total annual water availability including groundwater is about 1297 km^3, of which the three main rivers contribute around 1133 km^3. Of the latter amount, some 56 percent is contributed by the Brahmaputra, 30 percent by the Ganges and nearly 14 percent by the tributaries of the Meghna. However, the dry season (January-April) availability is only 88 km3 of which 74 km^3 is cross border flows (88%). The contribution of the Ganges in this case is 17 percent, the Brahmaputra 75 percent and the Meghna provides only 7 percent. The contribution from other rivers is negligible. It indicates that during the dry season Brahmaputra's contribution is vital for Bangladesh.

Because Bangladesh is the lower riparian country, water resources management is complex and very much dependent on upstream developments. Upstream infrastructural developments would result in adverse impact on the dry season flow. Changes in flows and sedimentation rates resulting from the development of the Farakka barrage is an example of how further upstream infrastructural development (and especially increased diversion of flows for irrigation consumption) would affect the downstream reach.

For the last few decades, India has been constructing barrages and dams on tributaries of the Ganges and Brahmaputra rivers, while also diverting water from these rivers for irrigation purposes. India is likely to continue the same path as irrigation plays an increasing role in India's economic growth and sufficient food for its rapidly expanding and urbanising population. Of particular interest for Bangladesh are the Indian proposals to construct 16 barrages on the Ganges River and the country's plan to divert water from the Ganges and the Brahmaputra rivers towards the South of India. In addition, India is planning to construct the Tipaimukh dam in the north-eastern part of the country. All these projects will impact the water availability in Bangladesh as well as the ecological condition of the rivers. Fisheries and agriculture activities within Bangladesh are expected to have adverse impact by these developments.

The proposed Indian river-linking project is expected to have a notable impact on the dry season flow. Among the major rivers, the Ganges has been found to be the most negatively impacted river, followed by the Brahmaputra and to a lesser extent, the Meghna. Other most impacted regional rivers are Dudhkumar, Dharla, Teesta and Mahananda, which indicates that a reduction of the low flow in the Teesta in recent years results in an alarming situation due to water withdrawal in the upstream Teesta in the Indian part. During the low flow season, the Mean Monthly Minimum Flow has decreased from139 m^3/s to 50 m^3/s (1967-2006). According to a study, the diversion of dry season flows from the Ganges, as a result of the construction of the Farakka Barrage, has caused considerable hydrological changes in the Ganges system within the country, notably a reduction in dry season flow and an increased siltation of the Gorai River (Mirza, 1997).

China is constructing hydropower dams upstream of the Brahmaputra River, in order to make use of the river's potential hydropower capacity. At the moment, relatively smaller dams are being constructed in order to create the opportune situation for the construction of the large Great Bend hydropower dam. This dam is estimated to generate 40,000 megawatts after its completion. According to the Chinese Government, these projects would have no significant impact on the river discharge downstream, as no water would be extracted. However, there might be ecological consequences, which are yet unknown. India and Bangladesh continue to remain concerned over water diversion from the upper part of the Brahmaputra to the North of China. Although such a large infrastructural project is regarded unlikely in the short term, dams constructed in China in the Great Bend of the Brahmaputra shows China has so far not disclosed about the diversion project (Figure 2.2).

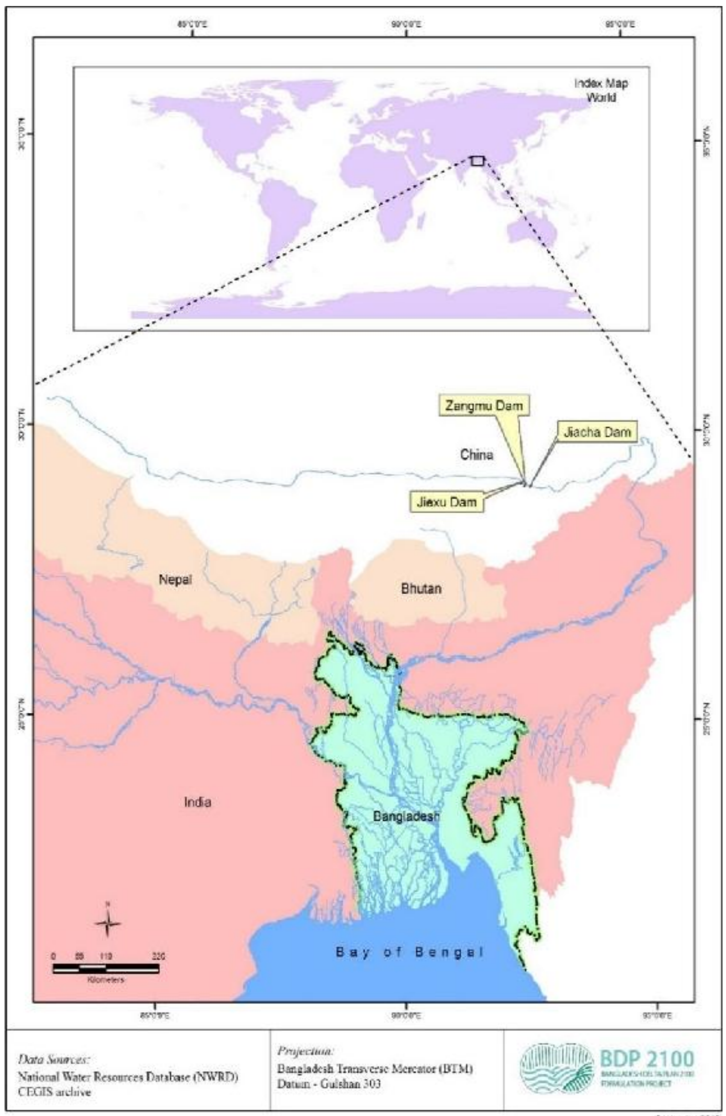


Figure 2.2: Location of Chinese Dams in the upstream of Brahmaputra River

Source: BDP 2100 Baseline Report

2.6 Salinity

The river water salinity in coastal Bangladesh depends on the volume of freshwater discharges from the upstream river systems, the salinity of the Bay of Bengal near the coast, and the circulation pattern of the coastal waters induced by the ocean currents and the tidal propagation to the river systems. Thus, average salinity concentrations of the rivers in the coastal area are higher in the dry season than in the monsoon because of lack of freshwater flow from upstream. Salinity level generally increases almost linearly from October to late May with the gradual reduction in the freshwater flow from the upstream. Observation of salinity shows an increase of salinity in Khulna from 0.7ppt to 16.8 ppt in the Rupsa River from 1962 to 2011 (50 years). It was observed from the field measurements that the maximum river salinity occurred during the dry season i.e. from October 2010 to May 2011.

However, the levels of river salinity in the adjacent south-central and south east coastal zones remain low. The low salinity (0 to 2 ppt) level in the south-central zone i.e. in much of the Barisal area for the whole year, results from the significant volume of freshwater flow from the Padma River and the Lower Meghna River through the Arialkhan, Buriswar, and Bishkhali Rivers. The problem of river salinity is most severe in the southwest zone. Salinity intrusion reduces the freshwater area that results in decrease of agricultural production in many parts of the coastal zone, especially the Khulna region and the extreme south of the Patuakhali region, and locally in the Noakhali and Chittagong regions. Increase of salinity is damaging the freshwater fish habitat and has adverse impact on the Sundarban ecosystems.

2.7 Groundwater

The shallow groundwater in the south western coastal region is generally too saline for domestic or irrigation use due to either connate (inborn) salts or estuarine flooding. However, sufficient flushing of saline water has taken place in isolated pockets to enable a limited domestic use of fresh water in the shallow aquifers. In the deep aquifer pattern, salinity distribution is more uniform on a regional basis, as is the continuity of the aquifer. The change from potable water to very saline water is sharp and occurs over a relatively short distance (IWM, 2014). Groundwater quality monitoring studies by Bangladesh Water Development Board (2006), Department of Public Health Engineering (1999), and the hydro-geological investigation by the British Geological Survey (1999), revealed that groundwater is generally fresh outside the coastal zone. However, 25% of the population was exposed to contamination exceeding Bangladesh Standards in 2001 (NWMP, 2001). About 14 districts are affected by salinity in the coastal belt with an affected population of about 12 million people in accordance with the BWDB study, 2013.

The result of the intensive groundwater extraction has been a gradual (in the case of Dhaka area: rapid) decline of both pre-and post-monsoon groundwater table. In intensively irrigated areas, groundwater level fluctuates between 5 to 15 meters below ground level, in some places even up to 23 meters during the dry peak irrigation season. In Dhaka city groundwater levels have fallen to 80m below ground level in the central part, as 85% of the water supply depends on groundwater. The obvious reason is the explosive growth of the number of tube wells for drinking water supply. Table 2.3 indicates the trend of tube well development in Dhaka from 1970 to 2014.

Table 2.3: Trend of tube well development in Dhaka City

Year	1970	2000	2005	2014
Nos. of Tubewell	49	300	423	690
Withdrawal (Mm^3/day)	0.18	1.2	1.5	2.5
Water Table (m)	0.5-10.5	19-41.5	19-54	24-71

Nonetheless, arsenic contamination in groundwater is another problem in water resources sector, found mostly in southwest, southeast and northeast region of the country. The contamination is least in the northwest and some uplifted areas of the north-central part. A comprehensive survey of the distribution of arsenic in groundwater was carried out in 1998-99 by DPHE with the technical support from BGS. More than 3500 tubewells were tested in 61 out of 64 districts (excluding the Hill tracts), which showed that water from 27% of the shallow tubewells (wells less than 150 m deep) exceed the Bangladesh standard for arsenic in drinking water, i.e, 0.05 mg/l, while 46% of the wells exceeded the WHO guideline value of 0.01mg/l in 2001. It is also evident that aquifers deeper than 200m are safer from contamination. However, arsenic mitigation options should include development of arsenic free groundwater sources, well-treatment of contaminated water and increase use of surface water sources in order to lessen the burden on groundwater.

2.8 Cyclone and Storm Surges

The entire southern boundary of Bangladesh is exposed to the Bay of Bengal and eventually to the Indian Ocean. Nearly every year, be it less severe or devastating, cyclones hit the coast and cause damage to lives and properties of the coastal population. The cyclone that hit in 1970 at greater Barisal caused nearly 300,000 deaths. But the one with almost the same severity in terms of wind speed hit in 2007 (the SIDR) took lives of nearby 3406 people. This is credited briefly to: improved cyclone warnings, more cyclone shelters, awareness building, and highly developed disaster risk management capabilities. Around nineteen major cyclones hit the coast from 1960 to 2009. After SIDR an extensive programme called Comprehensive Disaster Management Programme (CDMP) was launched to address all main hazards and to develop ways for disaster management in Bangladesh. In CDMP during 2013, the Storm Surge Study was conducted, in which hazard maps were developed for all 19 coastal districts up to upazila/union level.

2.9 Climate Change

2.9.1 *Sea level rise*

One of the most important impacts of climate change for low lying countries, like Bangladesh, is sea lever rise. Sea level rise is caused by global warming which affects two main processes. First of all, higher ocean water temperature causes thermal expansion and secondly, atmospheric warming results in the melting of land ice. Between 1901 and 2010 sea level has risen at a rate 1.7mm/year. Over the last 20 years the rates of sea level rise have increased. From 1993 to 2010, tide gauge measurements indicate a rise of 2.8±0.8mm/year and satellite altimetry data indicate a rise of 3.2±0.4mm/year.

Regional sea level rise:

There are regional differences in sea level rise; some areas could potentially experience more sea level rise than the global average. Regional sea level rise is for example, affected by the mosteric and halosteric circulation (Pardaens, 2011). The fifth IPCC report (2015) concludes that 70% of the global coastlines will probably have a sea level rise within 20% of the global mean sea level change (Church et al. 2013). For Bangladesh Delta Plan, it is important to know, if the sea levels in the Bay of Bengal will rise more or less than the global average. Brown et al. (2014) studied regional future sea level rise for Bangladesh. Regional sea level scenarios for the Bay of Bengal were developed based on the global scenarios by Hinkel et al. 2014. The result showed that sea level rise in Bangladesh is slightly higher than the global average mean. However, the differences between the global and regional scenarios are small in most cases less than 5% with a maximum of 10% higher (Brown et al. 2014). This means that by 2050 sea level rise could be up to 4 cm higher than global mean and by the end of the century up to 10 cm.

Relative sea level rise:

For most of the impacts of sea level rise such as salinity and increased flood risks especially the relative sea level rise is important. The relative sea level rise is also affected by subsidence and sedimentation. It is difficult to develop scenarios for subsidence and sedimentation at delta scale because these processes are highly variable. For more information, please refer to the Baseline study on 'Coast and Polder Issues.'

2.9.2 *Temperature rise*

The analysis on the data of BMD over 32 year period from 1977 to 2008 showed a rise of temperature by 0.016 °C/year, 0.02 °C/year and 0.012 °C/year for mean annual temperature, mean maximum temperature and mean minimum temperature respectively. For mean annual temperature, statistically rising trend was found in 19 stations out of 31 stations. For minimum temperature and maximum temperature, rising trend was found for 17 stations out of 31 stations.

Projection on temperature and rainfall: Two future projections (taking emission Scenarios A2 and B1) at 2030 and 2050 were built. Table 2.4 shows emission based future projections on change of temperature and precipitation at national scale (CDMP II, 2014).

Table 2.4: Projection on temperature and precipitation

Emission Scenario	Temperature change by °C		Precipitation change by %	
	2030	2050	2030	2050
A2	0.73	1.32	4.9	8.1
B1	0.78	1.62	6.3	8.4

3. Water Resources Planning

The water resources planning during the last sixty years' period went through different phases. The transition from one phase to the next mainly based on the socio-economic changes and needs. Over time, these needs changed as the country progressed and faced new challenges. The different phases of water resources planning processes and its main features are described in the following sections.

3.1 Initial Phase: Krug Mission

The development of water resources in the country started in the pre-independence period in 1952, when the-then government planned three water resources development projects. These were: i) Karnaphuli Multipurpose Project in Chittagong Hill Tracts for power generation and flood control in the Karnaphuli river for Chittagong city and adjoining areas, ii) Ganges-Kobadak (G.K) Project for providing irrigation in the then Kushtia and Jessore districts, and iii) Cross Dam Number 1 for reclaiming lands in Noakhali districts. The main characteristic of this phase, till 1970's, was a focus on large protection works for flood control and saving the agricultural croplands and habitats. After the floods in 1954, 1955 and 1956, a United Nations Technical Assistance Mission (popularly known as Krug Mission) was engaged to study the flood control and water resources development problems. Krug Mission Report is the first major study which addressed the problem of flood control and water resources development of the country. Based on the recommendations of the Krug Mission, East Pakistan Water and Power Development Authority (EPWAPDA) was established (Ordinance no. 1 of 1959). The report of the Krug Mission effectively discussed the principles governing delta development by large rivers and pointed recommendations, suggestions and observations of the report.

3.2 IECO Master Plan

The first national water master plan was prepared in 1964 by the American Consultants, International Engineering Company (IECO), suggesting implementation of 58 large flood control, drainage and irrigation (FCDI) projects which were gradually executed between 1955 to 1980 spanning a period of 20-25 years. The objectives were to develop the resources of the country as rapidly as possible so as to promote the welfare of the people, provide adequate living standards, social services, equality of opportunity and aim at the widest and most equitable distribution of income and property (IECO Master Plan, 1964). Following the Plan, the construction of large flood control, drainage and irrigation projects began in earnest. The orientation of all water sector development to this time was almost exclusively aimed at achieving the goal of increasing agricultural production to achieve national self-sufficiency. The main focus was on flood control and drainage as well as irrigation in a limited way. The approach was sectoral with limited inter-sectoral communication.

These projects were successful in agricultural crop production and rural employment generation but overlooked fisheries and navigation sectors. The objective of that plan was only to protect the area from flood and coastal storm surges and produced agricultural crops. The impact assessment was not considered for the other sectors, which in result, imposed some adverse effect on the FCDI projects of those sectors, i.e. the height of the river bed increased due to siltation, water logging in the south west region, decrease of hydraulic connectivity of water bodies, biodiversity, local species of fish and also decreased navigation routes.

3.3 Post-independence Phase

The investments in large FCD/I projects faced criticism, as these projects took a long time for realization and the benefits not trickling down to the poor. This led to study by IBRD during 1969-70 to review the investment and performance of the water sector and its findings published in a report entitled "Land and Water Sector Study" in 1972. This study advocated smaller-scale development, especially in minor irrigation. Although, this report was not approved by the government, the aid-giving institutions aligned their aid-portfolio to it. Despite all this, the implementation of large scale projects continued.

Again, a severe flood occurred in 1974 while the country was still recovering from the war and in need of increasing agricultural production. In this circumstance, the small-scale Early Implementation Project (EIP) was launched in collaboration with the Government of the Netherlands as well as EIP-Type Projects by ADB and other similar projects by CIDA. In the long-run, the strategy of developing small-scale FCD/I projects did not produce desired results, as the small-scale infrastructure were mostly damaged in the 1987/88 floods. However, the emphasis on minor irrigation and privatization resulted in a considerable increase in irrigated area.

3.4 NWP Phase

In 1983 the Master Planning Organization (MPO) was established. The first National Water Plan (NWP-I) was completed in 1987 where an assessment on the availability of water from various sources was made and also the future water demand of different users was estimated. As the tasks remained unfinished, the second National Water Plan (NWP II) was initiated in May 1989, and after a bridging period of 18 months, was completed in 1991.

During this phase, a substantial volume of information was generated. This included the development of a number of numerical models and analytical tools for defining and evaluating strategies. One important outcome of this process was the recommendation of strategies and programs, many of which were adopted by the government and endorsed by donors. Both phases of the NWP recognized the importance of fisheries and recommended several basic policies to strengthen fisheries institutions, improve the design of water control structures for providing fish migration, improve the management of FCDI projects to enhance fish production, and the need to reserve certain water bodies for fisheries development. Despite these achievements, "MPO reports fell short of a comprehensive national water plan" – as pointed out in Bangladesh Water and Flood Management Study (BWFMS, 1995).

In June 1991, MPO was transformed into Water Resources Planning Organization (WARPO) with a mandate to carry out the preparation and updating the National Water Plan. The creation of WARPO was gazetted on 22nd December 1991 with the mandate to "evolve national policies and strategies for utilization and conservation of water by all" (NWP). The newly restructured WARPO (from MPO) set out with an objective to carry out the preparation and updating of National Water Plan with appropriate inter-sectoral focus, and inter-disciplinary approach, particularly emphasizing environmental issues.

Although the Flood Plan Coordinating Organization (FPCO) was temporarily established as a coordinating agency for coordinating Flood Action Plan (FAP) activities, the organization was merged with WARPO soon after the completion of FAP in 1996. The Bangladesh Water and Flood Management Strategy (BWFMS, 1996), an outcome of FAP called for formulation of National Water policy and the preparation of National Water Management Plan (NWMP). WARPO initiated preparation of the National Water Management Plan (NWMP) in March 1998 and completed the preparation in December 2001. The NWMP was a framework plan to guide the stakeholders/ agencies to preparation of projects, and ministries and planning commission to identifying priorities towards fulfilling aim and objectives of NWPo. After this, the focus of water resources planning shifted to an integrated and a participatory water management approach.

WARPO functioned quite well for some time along with the FPCO under one roof until the NWMP was prepared. However, the organization was impeded by budgetary constraints, and mostly consisted of engineers deputed from BWDB, and thus missed a balance of economists, social scientists and environmentalists. In addition, the deputed engineers had divided loyalty, and never dedicated themselves in the business of WARPO. The multi-disciplinary structure was particularly important if the organization was to interface effectively with other agencies (BWFMS 1995). This weakness plus the lack of developing its own technical staff existed for a long time and played a key role in gradually becoming an ineffective organization at a later stage.

The NWP I and II emphasized the role of minor irrigation with LLPs and STWs. In response to this, in 1992 the National Minor Irrigation Development Project (NMIDP) was launched by the Ministry of Agriculture with the principal objective of consolidating the transition of minor irrigation from a supply driven public sector to a demand driven private sector one. There has been widespread growth of minor irrigation as a result of privatization, easy technology and reduction of government taxes on the equipment.

NWRC: The National Water Resources Council (NWRC), established in 1983, with representatives from all water-related ministries and chaired by the Prime Minister, is the highest national body for the formulation of water policy. It received recommendations from an Executive Committee (ECNWRC). This council approved the National Water Policy and National Water Management Plan. The NWRC was reconstituted as per Bangladesh Water Act, 2013. It coordinates different water agencies and makes recommendations on all water policy issues to the cabinet such as integrated development, proper use, safe abstraction, proper distribution, protection and conservation of water resources. The NWRC may also give advice to the Government to enter into any memorandum of understanding or treaty or any other similar instruments with any foreign country, government of international or regional organization. The Government, in consultation with the council, may engage in the exchange of data in respect to common water resources, undertake joint survey or study on international rivers, take measures for development of water resources and organize educational or training programs on water resources.

3.5 FAP Phase

As an aftermath of two severe floods in 1987 and 1988, comprehensive studies on water resources were undertaken with the help of the international community which came to be broadly known as Flood Action Plan (FAP). The FAP was activated with periods extending from 1989 to 1995; some even extended up to 2000 (FAP - 21/22). The concept of 'controlled flooding' was adopted to be implemented over the next 20-30 years. The FAP was observed as a five-year rolling plan to be implemented over a period of 20-25 years that would be reviewed every two years. Various plans of action were put forward ranging from improved flood forecasting and warning systems to high cost embankment schemes aimed at changing the entire hydrological regime of the country. The Flood Action Plan (FAP) included 26 main components (11 main components and 15 supporting activities under different plans) and a special Macro-Economic Study. A separate organization, named "The Flood Planning Coordination Organization (FPCO)" was established to manage these studies of FAP.

FAP Studies were massive and in many respect very thorough in terms of technical and social information. Another benefit was a series of planning guidelines under different themes such as EIA, SIA, project assessments and people's participation. The comprehensive guidelines prepared under EIA was highly recognised and formally adopted by the government to make it mandatory for any project of the water resources. However, many criticisms were observed NGOs against the FAP approach and outcome, as being too technical rather addressing the environmental and social aspects in the studies. In 1992, after much debate, it was agreed to prepare a guideline for involving the local community in water management. This was undoubtedly a major departure from the existing approaches.

A number of priority projects was selected under FAP to address the aforementioned problems and issues. The priority projects included short-term (1-5 years) and medium-term (6-10 years) to long-term (>10 years) projects. Short-term projects would address problems where there was clearly a need for early action, and medium to long-term projects included those which the regional studies showed generation of significant social and economic benefits while causing least damage to the environment. One of the outcomes of the study is the Bangladesh Water and Flood Management Strategy (BWFMS) – 1995 (FPCO-1995), which was, endorsed by the Government. The BWFMS, considered as the main strategy document of the FAP studies, not only focused on flood management, but identified social, economic and environmental constraints for the development of the water resources sector. Following the recommendation of the BWFMS, the institutional arrangements for planning of water resources were reviewed leading to the merging of the FPCO into an expanded WARPO in 1996. The strategy recommended preparing a National Water Policy and a National Water Management Plan. The Policy was adopted in 1999.

Though the FAP study on Institutional Development covered the management and operational aspects, making WARPO as solely responsible for carrying out the water resources planning and design was a wrong thinking and short-sighted, which was proved a few years later. Merging of WARPO and FPCO in a single planning organization for water resources worked fine for few years during the FAP planning phase, but eventually, the union did not work as desired.

FAP was the result of coordinated efforts of the various donor agencies including World Bank, ADB, UNDP, and USA, Canada, Japan and other European countries. As such, the formulation of projects under FAP was donor driven. Inter-sectoral integration among water, agriculture, fisheries, environment and navigations was not achieved in the absence of IWRM practice. As a result, after completion of about 44 projects, no work was carried out for the remaining 111 projects.

3.6 NWMP Phase

NWPo: The GoB adopted the National Water Policy (NWPo) in 1999 to streamline the activities in water sector. The policy provides the guidelines for agriculture, fisheries, industry, navigation, environment, basin-wide planning, water rights and allocations, public and private investment, water supply and sanitation. The policy underscores the broad principles of water resource development and its rational utilization. It emphasizes both public and private actions and highlights the importance of conjunctive use of ground and surface water. WARPO has a mandate to ensure coordination of all relevant ministries through the NWRC and to plan all aspects of water development including major and minor irrigation, navigation, fisheries and domestic water supply. It is a document that gained appreciation from the international community. Other relevant policies adopted subsequently were as follows: National Environment Policy (1992), National Forestry Policy (1994), National Energy Policy (1996), National Fisheries Policy (1998), National Policy for Safe Water Supply & Sanitation (1998), National Agricultural Policy (1999), Industries Policy (1999), National Land Use Policy (2001), Coastal Zone Policy (2005), Coastal Zone Strategy (2006) etc.

The NWPo stated national goals which formed the basis for the development Strategy for the NWMP. This Strategy, agreed by Government as guideline for the NWMP, placed equal importance on each of the national goals, i.e. economic development, poverty alleviation, food security, health and safety, standard of living and environment. Consequent upon the declaration of the National Water Policy (NWPo) by GOB in January 1999, Guideline of Participatory Water Management (2001) was initiated for formulating a common Guideline to avoid conflicts and duplications. Subsequently, the National Water Management Plan **(*NWMP*)** was approved by the Govt in 2004.

Coastal Zone Policy and Strategy: The Coastal Zone Policy was formulated through a process of multi-level consultation over a period of two years and approved in January, 2005. Integrated Coastal Zone Management (ICZM) was the fundamental to development of the Coastal Zone Policy. Subsequently, a Strategy was developed, for implementing the policy, as to select strategic priorities and actions on the creation of the institutional environment that will enable the Govt to embark on a continuous and structured process of prioritization, development and implementation of interventions for the development of the coastal zone.

Master Plan for Haor area: A Master Plan for Haor Area was formulated in 2012, containing 154 projects in the investment portfolio, placed under 17 Development Areas. The overall goal of the Plan is to achieve sustainable development by integrated planning and implementation through multi organizational involvement and community participation for optimum utilization of resources and reduction of poverty. This 20-year Master Plan is a framework plan which would be implemented on the Short, Medium and Long term basis. This plan also spells out the means for optimizing available resources of the area for future development by incorporating all relevant social and environmental considerations. To be more precise, integrated development would comprise mainly flood management, environmental sustainability, production of crop, fisheries and livestock expansion of education, settlement and health facilities, road communication, navigation, water supply and sanitation, industry, afforestation, and generation of power and energy. The investment portfolios have been prepared for 17 sectors namely Water Resources, Agriculture, Fisheries, Pearl Culture, Livestock, Forest, Education, Health, Transportation, Housing and Settlement, Water Supply and Sanitation, Industry, Energy and Power, Mineral Resources, Biodiversity and Wetland, Tourism and Social Services.

National Water Act (2013): The Government formulated the National Water Act in 2013. The Act stipulates the formation of National Water Resources Council (NWRC), chaired by the Prime Minister and consisting of 11 ministries, representative from department in concerns and nominated national experts. Article 5 of the Act stipulates its functions, including the formulation of policies and guidelines for integrated development, sustainable use, equitable distribution and conservation of water resources.

***Participatory Water Management Act, 2014*:** This Act was enacted in 2 February, 2014, according to Section-25 and -6 (1) of BWDB Act (2000). It is the final formal documentation of Participatory Water Management Approach in Bangladesh. PWMA, 2014 gives direction for maintaining Participatory Water Management in the following sectors, as: (i) Participatory Water Management definition and process; (ii) Definition of stakeholder, beneficiaries and PAPs, (iii) Legal authority of WMO, (iv) Structure, function and responsibilities of different level of organogram of WMO, (v) Membership process and Registration process and (vi) Financial Control and Auditing process.

Ganges Water Sharing: Bangladesh has 57 trans-boundary rivers, out of that 54 rivers are flowing into the country from the Indian Territory and rest from Myanmar. The transboundary waters are progressively reducing, especially the dry season flows. Traditionally, the country is highly dependent on these river flows.

After India completed the construction of the Farakka barrage in 1974 about 20 km upstream of the international border to divert waters, the dry season flow of the Ganges was severely reduced and the downstream was adversely affected. After a long negotiation, Bangladesh concluded an agreement with India in 1977 for five years. On the expiry of this agreement, Bangladesh signed a Memorandum of Understanding (MOU) in 1982 with India on the issue of the sharing of Ganges water. Again, in 1984 and 1986, MOUs were signed with some changes. After 1988, there was no agreement between for sharing the Ganges waters till 1996, when a 30-year Ganges Water Sharing Treaty was concluded. Between 1988 and 1996, India withdrew waters from the Ganges unilaterally.

Observation: The water resources planning, was initially need-based and area-specific. After the flood of the 1950s', some large flood control projects were taken up. The next decade saw changes in political and socio-economic conditions, and to realize the full potential as well as to minimize the adverse impacts of FCD/I projects, there was a need for updating the planning process adapted during the Master Plan period. Accordingly, the preparation of National Water Plan was undertaken and new planning and analytical tools were developed. More changes in planning took place after the severe floods of 1987 and 1988, when Flood Action Plan (FAP) studies were undertaken and the nature of floods and impacts were extensively studied.

However, there was a criticism of these studies as multi sectoral approach was not taken and community participation in the planning process was minimal. One of the outcomes of the FAP studies was the preparation of a strategy paper for water and flood management in the country in 1995 (BWFMS) followed by preparation of the National Water Policy in 1999 and the National Water Management Plan in 2004. The NWMP was a multi sectoral, integrated plan for water resources development of the country, prepared following elaborate and extensive consultation process with the stakeholders. However, due to inefficiency, lack of qualified professional staff and budget constraint, WARPO could not progress further and was never able to update the plan in next twelve years (2004-2016), when it was required to do it after every five years. Nearly US$ 2.0 billion was wasted.

The good thing that came out of various phases of water resources planning in the country is the new planning approach that has undergone many stages and refinement, responding to the socio-economic needs of the people. However, due to management and other problems, the updating and implementation of NWMP was not done, resulting in wastage of a long period, in addition to the huge amount of money as mentioned above. It is also observed that if the plan is not followed by execution, the plan would remain a paper work only, resulting in wastage, which a poor country like Bangladesh can ill-afford. Failure to carry out the assigned responsibilities should be accountable so that the defaulting staff made responsible for any inaction.

4. Review of FAP

The Flood Action Plan (FAP) was developed based on a series of regional studies following the major consecutive floods that occurred in Bangladesh in 1987 and 1988 which left catastrophic damage to crops, property, human life as well as infrastructure. Soon after the 1988 flood, the Government of Bangladesh (GOB) prepared the National Flood Protection Program which recommended the rehabilitation of all existing flood control and drainage (FCD) projects to tackle the recurrent flood problem. This followed by four major studies; Flood Policy Study by UNDP-Bangladesh team, Pre-feasibility study of flood control by French-Bangladesh team, Eastern Waters study by USAID and the review of flood management options by the Japanese team stressed that much of the technical, economic and environmental information needed to make choices between various options for addressing the flood problems was inadequate in the report prepared by the GOB. Thus in June 1989, the GOB requested the World Bank to organize efforts and prepare a program that would form a basis for a long term comprehensive flood management plan. The bank convened a meeting in Washington in July 1989 where delegates from Bangladesh and leading experts from original studies attended. The delegates expressed the necessity of the development of long-term strategies agreeing upon the prerequisite for comprehensive studies before implementation. It was decided to concentrate on an Action Plan for the next five years as the first step in formulating a long-term program, the central feature of which will be the regional studies. The experts involved in the four major studies, participated in the preparation of the framework of the FAP, which was presented at a meeting of the development partners in London in December 1989. The development partners agreed to provide $150 million for the FAP projects, the majority ($50 million) of which was allocated to the pilot projects for testing approaches to river bank protection and floodplain management. The FAP included 26 component studies which were supported by UNDP, the European Union, the Asian Development Bank, the World Bank and eleven bilateral donors (UK, Japan, France, Canada, Finland, Sweden, USA, Switzerland, Netherlands, Germany and Denmark).

The regional studies were key elements of FAP. Bangladesh was divided into six regions, such as: North-West Region, North-Central Region, South-West Region, South-East Region and North-East Region, considering the geomorphic and agro-ecological characteristics using the rivers as the main boundaries for preparing the FAP.

4.1 Objective of FAP

The main objectives of the FAP were to:

- safeguard lives and livelihoods from the devastation of flood;
- improve agro-ecological conditions to increase crop production;
- enhance development of public facilities, industry and country's strongholds;
- minimize potential flood damage;
- create flood-free land to accommodate the increasing population;
- meet the needs of fisheries, navigation, communications and public health.

4.2 Context of FAP

The Flood Action Plan (FAP) included 26 main components and a special Macro-Economic Study. A list of priority projects has been selected under FAP to address the aforementioned problems and issues. The priority projects include short-term (1-5 years,) and medium-term (6-10 years) to long-term (>10 years) projects. Short-term projects address problems where there was clearly a need for early action and medium to long-term projects include those which the regional studies showed generation of significant social and economic benefits while causing least damage to the environment. A total of 65 projects were selected with a total investment of Tk. 101,271 million.

A series of supporting studies were conducted subsequent to FAP and that were reviewed by a Panel of Experts. These studies helped in learning from the past and thus introduce various planning tools that enhanced the database. Development of FAP comprised of up-to-date maps and use of state of the art tools (e.g. global positioning system, satellite images) and various accurate hydrological data. It was the first time that a plan of national scale was developed using technologies such as geographic information system, remote sensing, global positioning system, hydrodynamic modelling.

4.3 Main Components of FAP

The Flood Action Plan (FAP) included 26 main components.

4.3.1 *FAP 1: Brahmaputra Right Embankment Strengthening*

'Brahmaputra Right Embankment Strengthening' is a main component of Flood Action Plan, which was started on December 1990 and completed on February 1993. The total budget was 3.36 million US Dollar and which was funded by IDA. The Phase 1A of this component named River Bank Protection Project was completed in 1999.The main objective of the component are:

- To formulate a master plan for the long-term protection of Brahmaputra Right Embankment (BRE)
- At the same time, to initiate immediate measures at critical places where branches had occurred or appeared imminent.

Ten (10) hard points were selected for detailed design studies. Four (4) priority sites were identified and examined. These sites were subsequently included in the Phase 1 of the River Bank Protection Project. Due to unstable nature of Brahmaputra-Jamuna River, the channel which has broken into the Bangali river during the floods of 1987 and 1988 had moved more than a kilometer from the breach site by the time where river protection works were undertaken. Interventions at one of the four selected sites of the River Bank Protection Project aims to prevent the Jamuna river from establishing a permanent link with the Bangali river.

4.3.2 *FAP 2: North West Regional Study*

The study is a main component of Flood Action Plan, which was started on Jan 1991 and completed on Dec. 1992. It was funded by United Kingdom and Japan. The total budget was 4.60 million US Dollar. A little follow up of this study was there at the time of drafting the National Water Resources Management Plan (WARPO, 2006) though the Gaibandha Improvement Project was already listed as Government's Aid-worthy Projects in 2000. The main objective of the component is:

- Asses flood control and drainage options for reducing and managing floods in the north-west region
- To prepare a regional water plan

- To carry out feasibility studies of identified priority projects.

An interceptor drain in the north-east and a diversion drain in the south-west proposed in the Flood Policy Study were found infeasible in the feasibility study. The main components of the study are-

- Sealing the BRE
- Implementation of a 'green river strategy'
- The Gaibandha Improvement Project
- Development of the Teesta Right Bank
- Development of Flood Protection and drainage Measures
- Flood Proofing and Protection of towns and other Infrastructure
- Programs to Develop flood proofing and Navigation
- Programs capture fisheries loses

4.3.3 *FAP 3: North Central Regional Study*

'North Central Regional Study' - a main component of Flood Action Plan, funded by European Union and France, started on Mar. 1991 and completed on Dec. 1992. The total budget was 3.56 million US Dollar. Five planning sub-regions comprising the upper sections of the flood plains on the Jamuna left bank and the Old Brahmaputra bank were identified for FCD development within a 15 year planning time frame. The main objective of the component is to examine alternative water development scenarios as a basis for preparing a regional water development plan with emphasis on flood control and drainage measures required for sustained development of the regional economy taking account of social and environmental factors.

This component involves economic and sensitivity analysis of benefits and losses in engineering, agricultural and fisheries aspect, qualitative assessments of socio-economic and environmental aspects using a multi-criteria approach.

Among the selected sub-regions for FCD development under this component, Jamalpur Priority Project (FAP 3.1) was selected for an immediate feasibility study. The regional plan incorporated works are included in the Greater Dhaka Flood Protection Scheme (FAP 8A & FAP 8B) and the Tangail Compartmentalization Pilot Project (FAP 20).

The follow up activities of the project (except the ancillary works of the above mentioned projects and Jamalpur Priority project) was halted due to lack of funds in the years up to 2000. However, the flood embankment along the Jamuna right bank (between Jagannathganj and Bhuapur) was completed by Bangladesh Water Development Board.

FAP 3.1: Jamalpur Priority Project

'Jamalpur Priority Project ', funded by European Union and France, was started on Dec 1990 and completed on Feb 1993 with a budget of 2.85 million US Dollar. It was identified during the Flood Policy Study (UNDP, 1989b) as suitable for early development due to the location in the upper section of the Jamuna Floodplain. The project includes construction of embankments, inlet and outlet structures, flushing sluices, drainage works and pilot flood proofing schemes. It also involves a fisheries program. The main objectives of the component are-

- To develop a regional water resources management
- To develop flood proofing and drainage measures
- To improve the economic, social and environmental situation of the study area

A feasibility study of the engineering and institutional requirements for controlled flooding on the mainland and flood proofing on the adjoining char areas was carried out in association with the FAP 3 study in the year 1992. The potential economic returns were satisfactory at that time but by the end of the FAP period, there was no follow up to implement the project in the subsequent period up to 2000 due to change in the attitude of donors toward large scale flood management project. Still, the project managed to be in the list of Government's Aid-worthy Projects in 2000.

4.3.4 *FAP 4: South-West Regional Study*

'South-West Regional Study' is a main component of Flood Action Plan. It was funded by ADB and UNDP, was started on October 1991and completed on May 1993; the total budget was 3.84 million US Dollar. The study region included BWDB's south-west and south-central planning regions. The study included a pre-feasibility study of the Gorai Augmentation Project.

The south-west region experiences counteracting salinity intrusion in the rivers and groundwater especially in the dry season due to diminishing of diversion of the Ganges water into the Hoogly River at the Farakka Barrage of India. The government was concerned about the salinity intrusion as well as flood control and drainage of this region. The main objectives of the component are-

- To assist the government in formulating a comprehensive regional land and water resources development and management plan
- To identify a portfolio of priority projects for early implementation
- To increase the dry-season flow in Gorai-Madhumati River.

The proposed plan included a total of 25 projects for flood control, drainage and irrigation in the region. There was also a proposal of a barrage across the Ganges to increase the flow of Gorai River beyond the immediate developments to be done by Gorai Augmentation Project.

Only major projects have been taken up by the year of 2000. The proposed Ganges barrage and Tarail-Pachuria FCDI Project remained in the government's list of aid worthy projects. While projects such as, Gorai River Development (only the dredging portion not the structures that was actually proposed), Bhola irrigation Project Phase-II, South-West Area Water Management Project Feasibility study was funded by ADB.

4.3.5 *FAP 5: South-East Regional Study*

The study was funded by UNDP with a total budget of 2.20 Million US Dollar. It is a main component of Flood Action Plan It was started on December 1990 and Completed on July 1993. One of its component, entitled as Meghna Estuary Study (FAP 5A) was completed on 1998 and the follow up activities are still going on. The main objectives of the component are-

- To prepare a regional water resources plan which would provide the government and potential donors with a range of possible developments throughout the region
- To promote improved living conditions through flood control, drainage, irrigation, increased agricultural output and enhanced incomes in a balanced program over an extended period of time.

A feasibility study was carried out to identify the priority projects. The study identified 15 potential projects with a satisfactory economic rate of return. A feasibility study was carried out of the proposed Noakhali North Drainage and Irrigation Project. The plan included projects that are already in progress or in preparation, such as: Chandpur and Meghna-Dhonagoda Irrigation Project and the Gumti Phase-II Project. It also incorporated other FAP study plans affecting the region (FAP 7 and 9B). During the course of FAP5, a separate study tittled Meghna Estuary Study (FAP 5A) was identified. None of the projects had been taken up by 200. Noakhali North Drainage and Irrigation Projects, the Gumti Phase II Project and the Dakatia-Little Feni Water Transfer Project (for irrigation) were still included in government's list of aid-worthy projects in 2000.

FAP 5A: The Meghna Estuary Study

The study is a main component of Flood Action Plan and was carried out after the main phase of FAP activities (after 1994). The study was entitled as 'FAP5B' in the FPCO progress report. The study was funded by Netherlands, Denmark and World Bank with a total fund of 10.55 Million US Dollar. It was started in November 1995 and completed in December 2001. The study area included the estuarine islands together with a 500 m strip of land on the Noakhali mainland. It was designed to carry out surveys to provide a reliable data base for assessing morphological changes within the estuary as the basis for planning land reclamation, improved land use and provision of a higher degree of security for the resident population against cyclones, storm surges, bank erosion and salinity.

The draft development plan was submitted in 1999. It proposed a 10 years long development program prioritizing erosion control, land accretion, empolderment and proposing pre-feasibility studies for such projects. Pilot project activities were initiated on the Halim Char Erosion Control Works, Kukri-Mukri Cross Dam and tests for the Nujhum-Dip accretion project within the project period. An integrated Coastal Zone Management Office (ICZM) was opened early in 2000 to coordinate the follow-up Estuary Development Program (2001-05), the Second Coastal Embankment Rehabilitation Project then under preparation and an on-going Char Development and Settlement Project.

4.3.6 *FAP 6: North-east Regional Study*

North-East Regional Study is a main component of Flood Action Plan and was started in August 1991 and completed in December 2001. It was funded by Canada with a total budget of 14.60 Million US Dollar. The study incorporated an on-going CIDA-funded Haor Development Project. The main objectives of the component are-

- To prepare a comprehensive water management plan with a view to create an environment for sustained economic growth and social improvement
- To identify priority projects for implementations.

It is stated in the Draft Development Strategy for the NWMP (vol. 5) that FAP 6 is the only one among the five FAP regional study that addresses the broader development issues and highlights the need for future development to differ substantially from that of the past.

Three (3) of the eight (8) identified programs were concerned directly with agriculture. The other programs include urban water supply and sanitation, village flood proofing, water supply and sanitation, fisheries management, river dredging for improved navigation, biodiversity enhancement and sustainable management, institutional strengthening and development. A large number of small scale FCD projects were identified. A cautious approach to small scale FCD projects has been seen in FAP 6 while large-scale public irrigation development was not considered to be justified.

Follow up activities up to 2000 included feasibility study for the Kalni-Kusiyara River Management Project, implementation of the Fish Pass Pilot Project (in the Manu River Irrigation Project) and Kalni-Kusiyara Pilot Dredging Project. These two pilot projects were rated very successful in WARPO (2000b) evaluation. However, Embankment Rehabilitation Project Phase-II faced a donor withdrawal and continued till June 2004 by local support, yet the Phase-I was completed earlier.

4.3.7 *FAP 7: Cyclone Protection Project*

The project arose out of the Cyclone Protection Project IIa feasibility and design study which was already under negotiation between government and donors in 1987 and was later incorporated into FAP. It was funded by EU and France with a total budget of 1 Million US dollar. It was started in February 1990 and completed in May 1992. It is a main component of Flood Action Plan. The main objective of the component is to rehabilitate and strengthen existing embankments along the coasts of Bangladesh, large sections of which had fallen into a state of despair due to lack of maintenance and damage caused by a succession of cyclones and storm surges during the previous 20 years.

The Chittagong coast was struck by the April 1991 cyclone and received damages to the embankment as well when FAP7 study was in progress. Thus, the ToR were altered to include emergency repair works and the project was renamed as Coastal Embankment Rehabilitation (CERP). Nominally remaining within the FAP, the CERP essentially became an autonomous program, overseen by the World Bank and funded by a number of donors, which continued long after the end of FAP.

Emergency works in Phase I were completed within the FAP period along the Chittagong coast, including sections adjoining the Chittagong Export Zone and Chittagong Airport. The work included rebuilding of derelict embankment sections, replacement or repair of regulators and sluices, afforestation of the foreshore in places and building of a road on top of embankments. Rehabilitation works were extended to sea-facing coastal polder embankments in Noakhali District and the western side of the Meghna Estuary in the subsequent CERP Phase II. This were still in progress in 2000 and outside the FAP, complementary cyclone proofing work has undertaken in the cyclone shelter building program.

4.3.8 *FAP 8A: Greater Dhaka Protection Project and*

Greater Dhaka Protection Project is a main component of Flood Action Plan and was started in October 1990 and completed in May 1993. It was funded by Japan with a total budget of 3 Million US Dollar. The main objectives of the component are-

- To formulate a master plan for comprehensive flood control and storm water drainage improvement for the Dhaka Metropolitan are including Tongi and Narayanganj
- To undertake a feasibility study for flood control and drainage in priority areas identified in the master plan.

Priority areas were identified in the western part of Dhaka city, the DND polder and Narayanganj west. Though DND area was included in the list of projects in the Bangladesh Water and Flood Management Strategy, the extent improvement works are not clear from WARPO (2000b).

FAP 8B: Dhaka Integrated Flood Protection Project

Dhaka Integrated Flood Protection Project was started in January 1991 and completed in October 1992. It is a main component of Flood Action Plan ADB and Finland funded the study. The budget was 0.61 Million US Dollar. The main objective of the component is to carry out a feasibility study of the high priority areas identified in the FAP 8A master plan study.

Dhaka Integrated Flood Protection Project studied three areas on the eastern side of Dhaka city in addition to the western area studied under FAP 8A. The final report was submitted in September 1991. Priority was given in completing flood protection and drainage works initiated in the western part of Dhaka city immediately after the 1988 flood. Implementation begun in 1991-92 and was scheduled for completion in mid-2000.

4.3.9 *FAP 9A: Secondary Towns Integrated Flood Protection Project*

The Secondary Towns Integrated Flood Protection Project was funded ADB with a total budget of 0.61 Million US Dollar. It was started in May 1991 and completed in July 1992. It is a main component of Flood Action Plan. The main objective of the component is to study feasible ways to provide river-bank and flood protection works for Khulna and a number of medium sized district towns. Six towns were selected for priority study: Khulna, Kurigram, Panchagarh, Moulvi Bazar, Habiganj and Dinajpur. Integrated plans for each of the six towns were proposed including measures for solid waste handling, sanitation and slum improvement.

A limited amount of bank protection work has undertaken at Khulna, Panchagrh, Moulvi Bazar and Habiganj within the FAP period. More comprehensive flood protection, river bank protection, drainage, solid waste management were undertaken and completed in Kurigram and Moulvi Bazaar between 1994 and 1999. WARPO rated these projects as successful in their evaluation (2000b) except for the lack of adequate provision from local resources for financial sustainability.

FAP 9B: Meghna River Bank Protection Study

The study funded by IDA, was started in November 1990 and completed in July 1992 with a total budget of 1.16 Million US Dollar. It is a main component of Flood Action Plan. The main objective of the component is to examine feasible ways to provide short term measures to protect seven sites on the Meghna river and one on a neighboring part of the Dhaleswari river against on-going bank erosion.

The final feasibility report recommended for implementing priority protection works at Bhairab Bazar town and Railway Bridge of Munsiganj and Chandpur. The bank protection works at Chandpur have been continuing since 1972 to post-FAP period. WARPO (2000b) evaluates the Chandpur Irrigation Project costs as high (US $ 2.77 M per km in 1998 prices) and the erosion did continue despite all the efforts. Benefits per person protected have seen very high and there were also substantial benefits in urban infrastructure protection. So the social and economic benefits of this protection project are well justified.

4.3.10 *FAP 10: Flood forecasting and Early Warning Project*

The project on 'Flood forecasting and Early Warning' was funded by UNDP, Japan and ADB with a total budget of 8.71 Million US Dollar. It is a main component of Flood Action Plan. It was started in January 1991 and completed in November 1992. The main objectives of the component are-

- To strengthen and improve BWDB's existing flood forecasting and warning system
- To increase forecast lead times and quality by means of improved telemetry, radar coverage, radio links, data management and flood modelling.

The objectives of the project were achieved through a succession of donor-funded projects during and after FAP period. The Mike-11 modelling system was developed under FAP 25 to enable the Flood Forecasting and Warning Centre to produce daily river level forecasts for 16 points on the main rivers for 24, 48 and 72 hours' interval.

4.3.11 *FAP 11: Disaster Preparedness Program*

This UNDP funded project is a main component of Flood Action Plan and was started in April 1992 and completed in December 1993. The main objectives of the component are-

- To increase the efficiency and effectiveness of government's response to emergencies caused by natural disasters

- To expedite recovery for emergencies
- To ensure the measures were taken to reduce disaster risks
- To take such risks into account in development planning
- To increase the capacities of households and local communities to cope with natural disasters.

A Disaster Management Bureau was set up in 1993 (in the erstwhile Ministry of Relief and Rehabilitation, renamed the Ministry of Disaster Management) with the responsibility to develop a comprehensive disaster management plan with the assistance of UNDP. This plan was focused on non-structural ways to reduce exposure to disaster risk by improving public preparedness through warning systems in village level and effective arrangements for precautionary measures, rescue, relief and rehabilitation. The assistance of UNDP and UNICEF to build the capacity of the Disaster Management Bureau was scheduled to continue till 2001.

According to WARPO (2000b), Local Disaster Action Plans existed in some 60 thanas in mid-1999, especially in the coastal areas and local Disaster Management Committees had been set up in most district and thanas though the majority of these only exist in paper only.

4.3.12 *FAP 12: FCD/I Agricultural Review*

It is a supporting study component of Flood Action Plan. It was undertaken in parallel with FAP 13. The project was started in January 1991 and completed in February 1992. A total budget of 1.60 Million US Dollar for this project was funded by UK and Japan. The main objectives of the component are-

- To assess the agricultural economic, social and environmental impacts of existing FCD and FCDI projects
- To identify constraints to effective project management and recommend ways to improve project design, operation and maintenance
- To develop guidelines and criteria to be used in the planning, design, implementation, operation and maintenance of such projects.

The study used previous assessment of over 60 completed FCD/I project. It also carried out rapid rural appraisal surveys of 12 completed projects and more detailed project impact evaluations of a further five projects. The important findings of the project are:

- The wide diversity of conditions between and within project areas, highlighting the need for local investigation and beneficiary participation
- Faults in project planning, design and implementation, including failure to take internal and external drainage impacts adequately into account, over-runs in implementation time, and inadequate embankment compaction
- Inadequate operation and maintenance
- Continued damage by flooding within some project areas
- Strongly negative fisheries impact
- Inequitable distribution of benefits, with substantial numbers of losers, increased social tensions between gainers and losers and dissatisfaction with land acquisition processes
- Negative environmental impacts because of the reduction of wet land areas, declination in flood-related fertility of soil and adverse impact on fisheries
- An enormous range in economic internal rates of return: nine (9) of the 17 (seventeen) projects studied were considered to be viable and eight (8) was non-viable (of which, one had a zero return and two were strongly negative), with small projects working better than that of large scale ones

The findings of the study were very influential in determining the subsequent approach to FCD/ FCDI development within and after the FAP period.

4.3.13 *FAP 13: Operation and Maintenance Study*

Operation and Maintenance Study is a supporting study of the Flood Action Plan funded by UK and Japan with a total budget of 0.60 Million US Dollar. It was started in January 1991 and completed in August 1991. The main objectives of the component are-

- To identify the main constraints on effective operation and maintenance (O & M) of FCD and FCDI projects
- To draw up guidelines for ways of overcoming these constraints, both for existing projects and for new ones under FAP
- To recommend ways of maximizing participation of beneficiaries and mobilizing local resources for O&M.

The assessment and survey methodology were similar to FAP 12. Additionally, a trial was done to examined, assess and improve the O&M on several externally funded BWDB projects and projects by LGED. The main findings are:

- Though government had instructed LGED to take over responsibility for O&M on completed small scale FCD/I projects in 1985, transfer of responsibility had not taken place
- A general lack of public consultation in project planning and design and the linkage between BWDB and local government were very weak
- Sub-standard construction of some projects had resulted in projects that could not be operated or maintained satisfactory
- Operational difficulties were experienced because of inter Aila: poor project design, inactive local project advisory committees; absent, untrained or locally-influenced khalasis (operator of structures), frequent conflicts of interest over operating practices
- Most of the embankments visited had 50% or more of their length in poor condition because of inadequate maintenance
- Central government fund allocations for O&M were usually inadequate even to cover staff costs
- BWDB was not empowered to mobilize resources for its own use and very few cases of local participation were seen
- O&M manuals had rarely been prepared, existing ones were not in Bengali. Thus the existing ones are not so effective and appeared not to be in use
- The tasks, responsibilities and accountability of those involved in O&M were not clearly defined, training programs were inadequate especially for the lower level staffs.

4.3.14 *FAP 14: Flood Response Study*

Flood Response Study is a supporting study of the Flood Action Plan funded by USA with a total budget of 0.92 Million US Dollar. It was started in March 1991 and completed in August 1992. The study was carried out in 15 different Thanas selected to represent different types of floodplain hydrological conditions prioritizing relatively flood-prone areas. The main objectives of the component are-

- To assess the response to the 1988 flood of people living in different floodplain environment
- To assess possible impacts of measures to mitigate flood impacts
- To formulate guidelines to enhance people’s flood response that would be useful to other FAP projects.

The key findings of the study are:

- Flood characteristics and problems varied considerably between different floodplain environments, implying that mitigation programs and projects needed to be tailored to suit local conditions and preferences
- The two most frequently adopted household's preparatory measures were storing fuel and fodder
- Women have specific roles in storing grain and fuel, preparing food, providing drinking water, caring for children and repairing houses
- The main agricultural response to food losses was to increase production in the subsequent Rabi season
- In general, people wanted more timely flood warnings, protection from floods but not from 'normal' flooding.

The study team recommended to strengthen the role of local government (Thana and Union Parishads) and to integrate the flood measures provided by the NGOs and local government with the measures proposed by other FAP studies/projects. Guidelines were formulated jointly with FAP 23 to assist the planners with the integration of non-structural measures (flood response and flood proofing) with structural measures for flood control and drainage.

4.3.15 *FAP 15: Land Acquisition and Resettlement Study*

Land Acquisition and Resettlement Study is a supporting study of the Flood Action Plan funded by Sweden with a total budget of 0.42 Million US Dollar. It was started in January 1991 and completed in January 1992. The main objectives of the component are-

- To assess the social and economic impacts of land acquisition on affected families
- To assess how the land acquisition procedures and methods of payment could be settled
- To identify ways to ensure the future economic viability of resettled families
- To develop criteria and approaches to minimize land acquisition and to facilitate the rehabilitation of displaced families
- To develop criteria, guidelines and procedures for land acquisition and resettlement in FAP projects.

The study reviewed the legal and administrative framework for land acquisition and identified the loopholes, weaknesses leading to wide-spread public dissatisfaction due to under valuation of properties, delays in transfer of tittle and payment of compensation etc. The main recommendations were:

- To minimize the amount of land acquired for embankments and structures
- To optimize the alignment of embankments through an accurate assessment of costs and benefits of alternative options
- To minimize arbitration by involving public representatives and affected people in critical decisions
- To offer options of assistance for self-managed resettlement or physical resettlement on Khas land or in raised linear settlements alongside embankments
- To provide economic rehabilitation opportunities through preferential access to project-related benefits, for example: construction works, embankment berms and borrow pits, and/or enhanced employment opportunities resulting from projects
- To avoid fund shortages by improved assessment and disbursement procedures, and by gradually mobilizing more local resources from project beneficiaries
- To restructure the administrative framework to improve the land acquisition process and minimize hardships for affected people

- To introduce a modern land record system including eventually a computerized data base and digitized mapping.

4.3.16 *FAP 16: Environmental Study*

FAP 16 entitled as 'Environmental Study' is a supporting study of the Flood Action Plan funded by USA with a total budget of 4.04 Million US Dollar. It was started in January 1991 and completed in January 1992. The main objectives of the component are-

- To identify potential adverse environmental impacts of water development projects
- To prepare guidelines for project planners to avoid the such adverse impacts or to mitigate in future.

A comprehensive guideline for environmental impact assessment was prepared which was later adopted by the Ministry of Environment for national use (FPCO, 1992e). A number of case studies was carried out to assess demographic, health, disease, soil fertility and other environmental impacts of existing water development projects. A comprehensive study was done on the dynamic physical and socio-economic conditions in riverine char lands (ISPAN, 1993a). Several seminars, workshops and training were held on environmental impact assessment (EIA) to inform and enhance the skills of government officials.

At the end of the FAP period, FAP 16 activities were combined with those of FAP 19 and continued in a new organization named Environmental and Geographical Information Systems (EGIS) (now CEGIS) set up within WARPO.

4.3.17 *FAP 17: Fisheries Study and Pilot Project*

Fisheries study and Pilot Project is a supporting study of the Flood Action Plan funded by UK with a total budget of 3.40 Million US Dollar. It was started in December 1991 and completed in June 1994. The main objectives of the component are-

- To examine the interaction between floodplain capture fisheries and water development projects
- To prepare guidelines for assessing impacts of such protects on fisheries resources and the user community

The further objectives are:

- To assess the feasibility of the technical and development measures
- To compensate for or to reduce potential loss due to flood control measures which could be tested in a subsequent pilot project.

Filed studies were made inside and outside eight flood control projects representing full flood control, controlled flooding and partial flood control by submersible embankment including floodplain, beel, canal (khal) and river fisheries. No studies were made in South-East region. Which indicates that fully protected, pump drained, polder projects such as Chandpur and Meghna-Dhonagoda projects were not studied. The key findings are:

Regional Variation: Wide variations were found between regions in the relative importance of fish habitats, fishing methods and fish catches per unit area in unprotected floodplain areas and rivers. So each region should be treated separately in applying these findings for future flood control projects.

Fish Production: While full flood control seriously reduced fish catches through loss of habitats and cutting off migration of fish, the impact of controlled flooding and partial flood control varied between projects and was not negative for all the cases. Project impact depended on factor, like: degree of flood control achieved, fish densities, fishing effort, management of regulators, adverse impacts of rural road development outside project areas etc.

Fish Breeding: Reduction of 33% species diversity took place due to full flood control while the percentage is 4-25% for controlled flooding cases and the effects of partial flood control is very little. Among the affected species, the greatest impacts were observed on the migratory species and the lowest on resident floodplain species.

Fish Movement: Catches of migratory species including high value carps and catfish decreased with the increasing degree of flood control.

Fish Population: Catches become highly dependent on a reduced number of species with the increasing degree of flood control. Which also creates a risk of not getting sustainable fish population to meet the increased demand. A fish data base was established that provides quantitative base-line information on inland fish resources and fisheries of Bangladesh.

The proposed mitigation measures are:

- Preference for controlled flooding over full control
- Digging of canals to maintain links between perennial beels and rivers
- Modification of regulator management/ introduction of fish passes (if relevant) to facilitate fish migrations onto and off floodplains at appropriate times
- Regulations to prohibit fishing from or close to regulations and to protect fish breeding sutes and dry season refuges in water bodies
- Greater provision of bridges and culverts through roads to reduce the impedance of fish movements across floodplains
- Establishment of multi-disciplinary technical assessment unit within BWDB/WARPO to enhance project planning and operation, along with improvements in data collection, management and distribution.

The findings of the studies and pilot project were not available for use in FAP regional studies due to late starting of FAP 17.

4.3.18 *FAP 18: Topographical Mapping*

This is a service project of the Flood Action Plan funded by Finland, France, Switzerland and Germany with a total budget of 6.71 Million US Dollar. It was started in September 1990 and completed in April1994. The main objective of the component is to provide FAP studies and projects with up-to date aerial photography, satellite images and topographical maps. The works done under the study are:

- SPOT imagery on 1:50,000 scale taken in 1989 was obtained for the whole FAP area
- Imagery taken in 1990, 1991, 1992 and 1993 was obtained for the area crossed by the Brahmaputra-Jamuna river
- Airphotos on 1:50,000 scale were taken for about 22,000 km^2 for the North-Central Region
- Airphotos on 1:30,000 scale for 10,000 km^2 in the Jamalpur Priority Area and the FAP 20 Tangail and Sirajganj Pilot Project areas
- Airphotos for other areas were taken for the consultants working on FAP regional study
- Second and Third order levelling were done in North-Central and North-East regions
- Photo contour mosaic maps were produced on 1:20,000 scale with 0.5m contour interval for the Jamalpur area
- Photo contour mosaic maps were produced on 1:10,000 scale with 0.25m contour interval for the Tangail and Sirajganj area.

4.3.19 *FAP 19: Geographical Information System*

This is a supporting service project of the Flood Action Plan funded by USA with a total budget of 4.36 Million US Dollar. It was started in April 1991 and completed in June 1996. The main objectives of the component are-

- To set up GIS facility to assist other FAP studies and projects to provide relevant maps, images, GIS analysis and statistics
- To provide on-the-job training to FAP and other government and NGO personnel in GIS Technology.

The important outputs of the project are:

- A study of bank-line changes in the Brahmaputra-Jamuna river using satellite imagery for the period 1973-92 and maps made between 1765 and the recent past
- A digital analysis of satellite images depicts changes in coastlines
- Digital elevation modelling in conjunction with MIKE 11 flood model of FAP 25 to produce flood area and depth maps for various flood scenarios for selected areas including the FAP 20 Tangail Pilot Project Area
- To support FAP 16 in carrying out its environmental case studies especially the Char Land studies.

4.3.20 *FAP 20: Compartmentalization Pilot Project*

This is a supporting study of the Flood Action Plan funded by Netherlands and Germany with a total budget of 20.12 Million US Dollar. It was started in August 1991 and completed in June 2000. Two pilot areas were selected for the study:

- **Tangail**- where a horse shoe shaped embankment exists at a radius of few kilometers around the town
- **North to Sirajganj Town**- a site where the Brahmaputra Right Embankment had been subjected to frequent breaching by the river erosion.

The main objectives of the component are-

- To test the compartmentalization concept under real operating conditions, addressing relevant socio-economic, institutional and environmental issues
- To try out water management works
- To formulate the criteria and principles for the design, implementation and operation of water management projects for the FAP.

After initial surveys, the site near Sirajganj was abandoned and the concentration was put on Tangail district. There, the project provided sluices in the existing embankment and a fish-friendly regulator at the entrance of the Louhajong river. Detailed topographical, hydrological, agricultural, fisheries and socio-economic surveys were also carried out. A special attention was paid on institutional and participatory aspects of controlled flooding. The project eventually was extended till 2000. WARPO (2000b) stated that, only limited testing of compartmentalization despite of all the enormous efforts. The final conclusion (by WARPO) are:

- Technically complex design and operation
- Implementation involved a massive technical input from foreign and local consultants
- Long implementation period including a long 'learning curve'
- High capital cost (TK 84,500 per ha)
- High costing for future maintenance (estimated as: over TK 2,000 per ha)
- Uneconomic: the benefits would be insufficient to cover the O&M costs let alone any of the capital investment

4.3.21 *FAP 21: Bank Protection Pilot Project*

FAP 21 and FAP 22studies were undertaken together.

FAP 22: River Training and Active Floodplain Management Pilot Project

Both of the projects (FAP 21 and FAP 22) were funded together by Germany and France with a total budget of 38.56 Million US Dollar. It was started in December 1991 and completed in December 2001. The combined study was eventually extended to 2000. The main objectives of the component are-

- FAP 21: To test different structural methods of river bank protection at selected sites along the Brahmaputra-Jamuna river
- FAP 22: To test the feasibility of controlling river-bank erosion by diverting channels away from the threatened sites by means of floating screens, channel closure and/or dredging.

The trials were made at Bahadurabad on the east bank and at Kamarjani on the west bank of Jamuna river. The conclusion of the study is:

- Groins and Revetments- the main two types of bank protection were tested, both appeared suitable for controlling local bank erosion. But the long term effectiveness remains to be observed.
- Groins may have adverse effects on neighboring char land
- Revetments may be preferable from the viewpoint of navigation
- Groins and revetments are very costly with capital cost of TK 280 M and TK 284 M respectively per km and annual maintenance cost is 5-10% of capital cost
- Various practical problems were observed including land acquisition, inadequate beneficiary participation, the change in river path away from the protected area at Kamarjani just after a year of completion of the protection works
- Adverse impacts appeared to be insignificant.
- Social benefits from erosion control were considered as substantial.

4.3.22 *FAP 23: Flood Proofing Pilot Project*

Flood Proofing Pilot Project was funded by USA with a total budget of 0.30 Million US Dollar. It was started in November 1990 and completed in December 1991. This project covered the urban flooding only as flood proofing needs for rural areas were covered by the FAP 14 study. The main objectives of the component were-

- To identify possible measures to mitigate adverse effects of floods in unprotected urban areas
- To examine the identified measures through a pilot project

A subsequent flood proofing pilot project undertaken by CARE (funded by USAID) in Kurigram and Netrokona districts in 1996-98 covered only the rural areas. It included the Char lands of Kurigram and deeply flooded Haor areas in Netrokona. Rapid appraisal surveys were done in the six regional town, namely: Brahmanbaria, Tangail, Sirajganj, Faridpur, Sunamganj and Bhola. The survey covered private, business, professional, institutional and NGO interests. A comprehensive flood proofing programme was presented for consideration which would require coordination and cooperation between many government agencies, NGOs, and private people and institutions. Guidelines on planning flood proofing measures were prepared and issues in corporation with FAP 14. The findings were combined with the FAP 14 are:

- Flood proofing measures should be complementary to flood protection and flood preparedness measures

- Though individuals, communities and institutions implement many flood proofing measures, shortage of resources and information often limits their effectiveness
- Government and NGOs have given only limited attention to build flood shelters for communities living in valuable areas
- There is an increasing need for land use controls to prevent people's activities encroaching on and interfering with natural flood paths across floodplains
- For homesteads, the main needs are for protection of water supplies, livestock, culture, fisheries and grain and fodder storage
- Road and railway embankments need to be provided with adequate structure to allow the passage of floodwater and planted with vegetation on the slopes as protection against erosion
- Transportation problems during floods could be reduced by providing credit to boat purchase and ensuring adequate passages through road and railway embankments
- Better coordination is needed between those constructing private and public buildings and the agencies provided information on flood levels so that homes, business and offices can be made flood-proof
- Flood proofing measures should be designed directly to improve the conditions of the urban and rural poor who are disproportionately more vulnerable of floods
- Flood proofing measures need to take into account local needs and resources.

4.3.23 *FAP 24: River Survey Program*

River Study Program was funded by EU with a total budget of 8.75 Million US Dollar. It was started in June 1992 and completed in October 1999. The main objectives of the component are-

- To collect reliable hydrological and morphological data at key locations on the main river systems, especially during the monsoon season, introducing new and improved technology where appropriate
- To undertake special studies of the behavior of the river system
- To upgrade Bangladesh's institutional capability for rive hydrological and morphological studies by providing specially equipped vessels, installing new gauges and establishing a computerized data base.

River discharge and sediment transport data were collected at 11 stations along the main rivers on a regular basis over a period of four years. The data were used to calibrate BWDB's historical data. Detailed bathymetric surveys were made and repeated again at all the sites. The suitability of many different measuring techniques was tested for use in wide, unstable and turbulent rivers. A number of special studies were carried out to improve the understanding of river behavior in relation to the design of embankments and bank protection works, predicting bank erosion rates, modelling changes in flow into distributary channels, assessing sediment transfer patterns and modelling the impact of proposed FAP measures on river levels and morphology.

The final report of the project regretted that, the project lacked institutional embedding: no counterpart organization was appointed despite of having many outstanding results. Exchange of knowledge and experience with BWDB, BIWTA and other organizations was only marginal.

4.3.24 *FAP 25: Flood Modelling and Management Program*

Flood Modelling and Management Program was funded by Denmark and France with a total budget of 4.39 Million US Dollar. It was started in October 1990 and completed in December 1993. The main objectives of the component are-

- To develop a mathematical model linked to the MIKE-11 flood forecasting model of BWDB's Surface Water Modelling Centre (SWMC), which is combined with GIS technology
- To get data of river water levels, areas and depths of inundation on adjoining floodplains and ideally, the impacts of floods in terms of potential crop losses, population displacement, disruption of management as well as for the operation of flood control measures.

Technical guidance and coordination were provided by an external Coordination Advisory Team together with a Resident Model Coordinator. The important achievements are:

- Integrating MIKE-11 with a digital elevation model of the country's land area (developed by FAP 19)
- Developing and testing a flood model for the North-Central Region
- Developing and testing a flood model for FAP 20's Tangail compartment
- Assisting FAP 19 with ground-truthing of ERS-1 radar imagery during the 1993 flood season
- Preparation of flood depth and duration maps to assist relevant government agencies in flood impact assessment in cooperation with FAP 19
- Conducting workshops and training courses to demonstrate practical applications of the flood management model to a wide range of government, NGO and consultant users.

FAP 25 activities were continued by the Surface Water Modelling Centre (SWMC), with donor funding after the formal end of the FAP in 1995. WARPO (2000a) indicates that the SWMC was later established as a non-profit trust.

4.3.25 *FAP 26: Institutional Development Program*

This is a supporting study of the Flood Action Plan funded by UNDP and France with a total budget of 3.60 Million US Dollar. It was started in February 1990 and completed in February 1995. The main objective of the component is to assess the institutional requirements for planning, implementing and managing FAP projects

A needs assessment report was prepared by an external consultant in 1993 which was not accepted by the government of Bangladesh. A subsequent report by national consultants were made available. But it did not come up with radical solutions regarding institutional problems for flood control and management and national development activities.

4.4 Fundamental Concepts and Approaches of the FAP

The concept of the FAP was developed based on the emphasis that the adverse impacts of the socio-economic and environmental issues of natural hazards are mitigated. Subsequent to FAP, a series of supporting studies were conducted that were reviewed by a Panel of Experts. These studies helped in learning from the past and thus introduce various planning tools that enhanced the database. Development of FAP comprised of up-to-date maps and use of state of the art tools (e.g., global positioning system, satellite images) and various accurate hydrological data. It was the first time that a plan of national scale was developed using technologies such as geographic information system and remote sensing, global positioning system, hydrodynamic modelling.

The FAP approach was developed aiming at socio-economic and environmental improvement. This particular approach had to two fundamental principles in order to be implemented. The first was to anticipate the effects of alternative solutions to the land and water management problems based on the data and tools provided by the related studies. The second was to utilize the skills of experts in wide range of fields in a multi-disciplinary approach comprising of hydraulic engineering, agriculture, agricultural economics, soil science, fisheries, public health, social science and ecology. In order to follow a common approach for all the FAP projects, three significant guidelines were developed; Guidelines for Project Assessment (GPA), Guidelines for People's Participation (GPP) and Guidelines for Environmental Impact Assessment (EIA). The GPA was introduced so that all the FAP projects adopted a single approach for project appraisal and impact assessment. The GPP ensured the participation of all affected people throughout all the stages of the projects. Finally, the guidelines for EIA were developed to assess the outcomes of an existing project and extract management measures, to integrate it into the plan and make it socially, economically and environmentally viable.

4.4.1 *People's Participation Approach*

Special importance was provided to people's participation in the development of the FAP. The participation of diverse groups of people results in sustainable planning of the projects through expressing their requirements and thus recognizes problems and feasible solutions. This participation was initiated through the consultations from the Rapid Rural Appraisal (RRA) and Project Impact Evaluation (PIE) among the local people. These were followed by seminars at different levels, where participants were drawn from members of parliament, elected representatives such as chairman of Union and Thana Parishads, Government and non-government agencies, different socio-economic classes, representatives from occupational groups and journalists on a regional basis. People's participation played a crucial role in the development of the FAP which was ensured through rigorous consultation with the local people. The GPP has been made compulsory in the approach to people's participation in the development of the FAP.

4.4.2 *Socio-economic Approach to FAP*

Projects exhibit varying impacts on social development and economic distribution. This variation ranges from positive to negligible impacts as well as impacts indicating the rising of new socio-economic problems. Thus for the FAP, socio-economic surveys, public consultations and economic analysis were initiated in the socio-economic approach to the development of the FAP. Public consultations mainly included RRAs through multi-disciplinary team members whereas economic analysis mainly included the use of the economic prices of the projects, calculation of Economic Internal Rate of Return (EIRR) and the Net Present Value (NPV) of the projects and finally the sensitivity analysis to assess the reliability and robustness of the estimates of projects. The social issues considered in this approach were employment opportunities, changes in occupational structure, income distribution, land ownership, local participation, and avoidance of social conflicts, gender equity and quality of life. The treatment was followed in the case of economic analysis, although it depended on the considerations of mitigation measures. The GPA emphasized the incorporation of social and environmental effects and thus includes them in the analysis. Although it is not always possible to quantify these effects, a multi-criteria approach was followed in this case where the analyses were complemented by simple quantitative or qualitative analysis.

4.4.3 *Environmental Approach to FAP*

The environmental approach evolved from a pure engineering to a more multidisciplinary focus during the preparation of FAP. This development was initiated when the policy makers realized the fact that socio-economic development and environmental protection should balance each other. The approach adopted for EIA was directed at identification of the key issues, isolation of major negative impacts of proposed intervention and ways to mitigate the impacts of flood. Along with the EIA a Resource Allocation and Optimization Model (RAOM) was used to develop the understanding of the land and water resource limitations. This model investigated feasible allocations of both the land and water resources and sought optimal solution to best satisfy the objectives set for the FAP. Although guidelines for the EIA developed for the FAP was followed in the environmental approach, the direct reliance of people's survival on the environment introduced various significant features in the EIA processes.

4.5 Synergies and Gaps

The floods of 1987 and 1988 and the concurrent damages was the main factor behind the initiation of FAP. The main concern was on how to protect an economically depressed country like Bangladesh from the negative effects of flood on the verge of its ongoing growth. As such flood control became the main focus of the FAP study. The study has both positive and negative influence on the development track of the country.

4.5.1 *Engineering aspects*

Floods in Bangladesh can be managed in 3 ways: flood reduction, flood proofing and controlled flooding. FAP introduced the concept of controlled flooding using embankments and compartmentalization, a simplified engineering solution for flood. This allows flooding up to a level (beneficial flooding) which is suitable for agricultural production and in the same time does not cause any damage to settlements or infrastructures. Embankments provide protection to settlements and other land uses e.g. agriculture, infrastructure, property and industry from river floods. Added benefits include protection from salinity intrusion, cyclones and storm surges in the coastal areas. FAP was praised for including both structural and non-structural measures to mitigate flood. In the coastal zone as well as the urban/town or cities, the polders are effective in safeguarding life and properties from river flooding.

4.5.2 *Environmental aspects*

One of the major concerns raised about FAP was that too much emphasis was given on flood control rather than management and the approach lacked multidisciplinary thinking. Reliance on embankments as flood protection measure has the following consequences:

- Embankments are under designed for cost considerations. These embankments fail in the face of mega events such flood and storm surges damaging expensive lives, settlements and crops.
- Inside the embanked or poldered areas, the river beds are raised causing water logging problems e.g. the coastal zone in the southern part of the country.
- Shifting of river course in a morphologically dynamic country like Bangladesh lends the river embankments unusable.
- Sometimes poor landless people are seen settling in on top of the embankment. They threaten the safety of the structure by building make-shift houses on it.
- Local people breach the embankment as a solution to localized flooding problem when the water in the river exceeds the danger level and enters the settlements.
- Due to water congestion in the poldered areas, health diseases such as diarrhea, malaria and other diseases and pollution from sewerage waste disposals.
- Water transportation is inhibited by the embankments. As a way out, sluice gates and locks are built so that the boats can pass. However, constructions of lock gates involve high cost and maintenance.
- Migration of fish and their free movement is restricted which hampers fish growth. This discourages capture fisheries and promotes culture fisheries. On environmental grounds, the fisheries experts are highly against the practices of culture fisheries.

- The embankments prevent the deposition of sediments on the flood plain areas. Lack of sediment supply in the long run lowers the soil fertility thereby decreasing agricultural production.
- Recharge of groundwater is reduced due to the low flow of the surface water
- Grazing land for the livestock is reduced as the land is used for construction of embankments

4.5.3 *Institutional aspects*

The FAP study on Institutional development thoroughly covered the operational aspects except the legislation and regulation components. Institutional capabilities of water sector institutions were assessed regarding water management, inter-agency linkages, people's involvement in different phases of project planning and implementation. Institutional gaps were observed in respect of institutional structure, learning capacity, accountability and handling of mega scale projects by BWDB. So, with the aim of enhancing the institutional structure, the critics appreciated the suggestions made by FAP of making WARPO solely responsible for carrying out its mandated tasks of planning and design. Merging of WARPO and FPCO in a single planning organization for water resources was suggested to ensure efficient and integrated planning of water resources. BWDB as an engineering based agency is to continue its activities for implementation of water resources projects.

4.5.4 *Tools and approaches*

The FAP made available tools and framework for in depth analysis of issues on water management, river training, flood mitigation and drainage. FAP for the first time demonstrated the application of tools such as geographic information system and remote sensing, global positioning system, hydrodynamic modelling.

The approach of Integrated Water Management (IWRM) was not entirely followed during the FAP project preparation. As such, though the flood control from engineering point of view was attained, it failed to take into account the issues of environmental sustainability and social security. However, Environmental assessments under FAP considered in detail the land and water interactions e.g. surface and ground water availability, impact of climate extremes etc. In line with the FAP studies, later on it became mandatory for every environmental or feasibility project to conduct EIA.

4.5.5 *People's participation*

People were involved during the preparation of FAP but in a very small scale. The project objectives were briefly mentioned to them at the beginning of the project. Focus Group Discussion (FGD) with the grass root people was not done. Hence, people's opinion on the project was not fully reflected. Gender issues were not considered as the women were not involved during the need assessment phase. So the needs of women regarding collection of water were ignored. The water user's group consisted of local elites and inexperienced people in solving water management problems. As a result of which, a sense of ownership about the project was not developed among the people.

4.5.6 *Institutional and sectoral integration*

FAP was the result of coordinated efforts of the various donor agencies e.g. the World Bank, ADB, UNDP, Canada, UK, Denmark, Finland, France, Germany, the Netherlands, Sweden, Switzerland and the USA. As such formulation of project under FAP was donor driven. The shortcomings of earlier water sector projects also were inherited to some extent into the FAP projects. Inter-sectoral integration among water, agriculture, fisheries, environment and navigations was not achieved in the absence of IWRM practice.

5. Review of NWMP

5.1 Introduction

After the National Water Policy (NWPo), prepared in 1999, the National Water Management Plan (NWMP) was formulated in order to operationalize the directives given by the NWPo. The NWMP is a pragmatic and sustainable water management plan in the light of National Water Policy, which has been adopted by the National Water Resources Council. The plan provided a framework for development, management and use of water resources and water services in Bangladesh. It is expected that the respective public agencies will plan and implement their own activities in a coordinated and integrated manner following the plan. The plan is presented in three phases: in the short-term (2000-05) it is considered a firm plan of ongoing and new activities; in the medium-term (2006-10) it is an indicative plan, and in the long-term (2011-25), a perspective plan. Implementation of the plan would be monitored regularly and it would be updated every five years.

5.2 Goals and Objectives

NWMP has been prepared to respond to the main water resources challenges, with three central objectives consistent with NWPo aims and national goals. These objectives are:

- Rational management and wise use of Bangladesh's water resources,
- Safe and reliable access to water for food production, health and hygiene, clean water in sufficient and timely quantities for multi-purpose use;
- Preservation of the aquatic and water dependent eco-systems.

5.3 Context of NWMP

The National Water Resources Council has approved this plan in 2004. This is an action/operational plan of the National water policy 1999. The plan has three phases: short term (2000-2005) to plan the ongoing projects/ activities, Medium-term (2006-2010) which is an indicative plan, and a long-term (2010-2025) which is a perspective plan. The projected population in 2025 is 181 million and in 2050 is 224 million. Due to rapid urbanization, 40% of people expected to live in towns and major cities in 2025 and about 60% in 2050. Therefore, the policy has the goal to meet the expanding demand of safe water in the country. The context of planning is:

a) *Socio-economic aspects:* Population growth; urbanization; poverty alleviation; economic growth and development; employment; public participation; education and public health; and food security were the major concern of the plan.
b) *Environmental aspect:* Pollution in surface water in rivers, pollution of groundwater especially Arsenic contamination of shallow aquifers has been identified as a major problem. The presence of iron, boron and other contaminants in groundwater are lesser but still important concerns. Capture fishing on the floodplains and haor basins, is a traditional activity of the poor, but is declining rapidly, for which immediate measures are suggested. Land degradation in the upland areas and deforest-action and landslides in the hilly areas contribute to increased soil erosion and impacts on the river systems. Eco-sensitive areas like Sundarbans and Haors (Large natural wetlands in the North-Eastern region of the country) are under great pressure from being encroached and the overuse needs special attention.
c) *Water Resources and Demands:* The river systems are the life-blood of Bangladesh. The history, economy, literature and rich culture of the people are influence by its rivers. They provide an arterial transportation network for people, goods and fish migration, and keep salinity intrusion at bay in the coastal areas. During

monsoon, 20% of the country is flooded and during peak period, it reaches as much as 60%. Projected sea-level rise of up to 44cm by 2050 will worsen flooding and drainage problems. More intense rainfall with climate change, frequent cyclonic storms and surges are apprehended. On the other hand, the country is experiencing tremendous water shortages during dry season from November to May. Farmers have turned increasingly to tube wells for irrigation, wherever possible and wherever surface water is not readily available. Seasonal water tables are reaching lower levels, impacting on hand-tube wells, which are commonly used for rural water supply source. Demands in the dry season will continue to increase as more land is irrigated and as water supply requirements increase. Climate change will exacerbate this situation.

5.4 Policy and Strategic Framework

The National Water Policy (NWPo) and the Development Strategy constitute the main policy and strategic framework for the NWMP. Besides these, a wide range of policies for various sectors has direct or indirect bearing on the water sector. These include: National Environment Policy (1992); National Forestry Policy (1994); National Energy Policy (1996); National Fisheries Policy (1998); National Policy for Safe Water Supply and Sanitation (1998); National Agricultural Policy (1999); Industrial Policy (1999), etc.

Strategic priority/Focused areas: The strategic guideline for the plan places equal importance on each of the national goals: economic development; poverty alleviation; food security; health and safety; standard of living; and environment.

There are many different technical issues to address in improving water resources management in Bangladesh. The priority issues are broadly the river maintenance, erosion control, land accretion and coastal zone management. There are also some fundamental issues that impact on medium and long-term planning, and further research is suggested on the following issues: Arsenic; Groundwater resources; Climate change; Natural environmental water requirements; Long-term implications for water management; decentralized water management; Promotion of private sector participation.

Cross-cutting issues: The following cross-cutting issues are equally important to address, and in fact consists the major components of NWMP: Institutional Development; Creation of an Enabling Environment (Decentralized water management; Cost sharing and cost recovery; Private sector participation; Community participation; Non-traditional financing modalities; Regulation separated from supply; New rights, obligations and accountability); Main Rivers (MR); Towns and Rural Areas (TR); Major Cities (MC); Disaster Management (DM); Agriculture and Water Management (AW); Environment and Aquatic Resources (EA).

5.5 Major Issues Identified in NWMP

The Plan is based on eight distinct and well defined hydrological regions. Major issues specific to the regions are:

Southwest Region: Preservation of the Sundarbans; Restoration of dry season freshwater inflows to the region; Maintenance of the coastal embankment system; Alleviation of coastal drainage congestion; Improved cyclone protection; Remedial actions for existing FCDI schemes; Flood proofing needs in the char-lands and low lying areas.

Northeast Region: Environmental management of the Haor Basin; Flash flooding and remedial actions for existing FCD schemes; Flood proofing of villages in the Haor Basin; Erosion of old Brahmaputra left bank; Drainage congestion in the Kalni-Kushiyara and other rivers; Local development of hill irrigation.

North Central Region: Bulk water supplies and pollution clean-up for Dhaka City; Encroachment on Buriganga and other rivers and channels in Dhaka; Flooding and drainage problems in parts of the region; Flood proofing needs in the char-lands and low lying areas.

Northwest Region: Erosion along the right bank of the Brahmaputra; Flooding and drainage problems; Remedial measures for existing FCD(I) schemes; Drought in the western fringes, especially the High Barind; Flood proofing needs in the char-lands and low lying areas.

South Central Region: Maintenance of the existing coastal embankment system; Siltation and drainage congestion; Improved cyclone protection; Flood-proofing needs in the Char-lands and low lying areas.

Southeast Region: Gaseous aquifers; improved cyclone protection; Maintenance of the existing coastal embankment system and drainage congestion; protection of newly accreted lands against tidal flooding; remedial action for existing inland Flood Control, Drainage Irrigation (FCDI) schemes.

Eastern Hills Region: Small-scale irrigation development in the CHT; Mini-hydropower development in the CHT; Improved cyclone protection in the Coastal Plain (CCP); Maintenance of the existing coastal embankment system.

Rivers and Estuary Region: An affordable long-term strategy for erosion protection; An affordable long-term strategy for regional augmentation; Flood proofing needs in the char-lands and low lying areas; Improved cyclone protection in the Meghna Estuary; Erosion of Meghna River; Land accretion and land reclamation; Timely protection on newly accreted lands.

5.6 Sectoral Clusters

The plan identified 84 programmes which are grouped both into eight sub sectoral clusters, as well as eight planning regions. The eight sub clusters are the following: *Institutional Development*, *Enabling Environment*, *Main Rivers*, *Towns and Rural Areas*, *Major Cities*, *Disaster Management*, *Agriculture and Water Management*, and *Environment and Aquatic Resources*. These programmes were spread over eight planning regions, i.e. South West Region, North East Region, North Central Region, Northwest Region, South Central Region, South East Region, Eastern Hills Region, and Rivers & Estuary Region. Priority is given to the institutional development, enabling environment, and water supply and sanitation. The estimated investment cost of the plan over 25 years is Tk 91,457 crore ($18 billion). The rationale of the clusters and the planned programmes are described below.

Institutional Development: The implementation of the programmes listed in NWMP requires the development of the institutional capacity of the relevant agencies. The purpose is to develop each institution on sound principles, which are to separate the tasks of policy formulation, planning, and regulatory functions from the implementation and operational functions, while at the same time to make these institutions accountable for financial and operational performance. Among the programmes under this cluster, the capacity buildings was important one: Capacity building of Local Government (for water management), BWDB, WARPO, DMB (now DDM) and other organizations.

Enabling Environment: The programmes under this cluster have been designed to create an enabling environment through measures that will make clear the rights, obligations and rules of business required for the sector as a whole. These measures will embrace legal and regulatory reform, research, improved information management and dissemination, application of economic instruments and introduction of alternative funding mechanisms. The programmes developed are given below: water sector legislation, project preparation and participatory water management – guidelines and manual, NWRD improved data collection & processing, R&D studies, private sector participation for water management, alternative financing methods for water management.

Main Rivers: The main river systems are planned to be comprehensively developed and managed for multipurpose use through a variety of structural and non-structural measures. Comprehensive planning of the main and subsidiary river systems will be undertaken by the responsible agencies, integrating the needs of all users with sound environmental principles. Planning of international river basin needs to be pursued to realise the full potential benefits of these rivers. The programmes developed under the plan are given below include mainly: main river studies and research programmes, Ganges, Meghna and Brahmaputra Barrages and ancillary works, NE, SE, NC and NW and GDA regional surface water distribution networks, main river erosion control at selected locations, river dredging for navigation and hydropower development and upgrading.

Towns and Rural Areas: The NWMP aims to provide affordable, safe and reliable supply of potable water and sanitation services to all people on an equitable basis in order to safeguard public health and protect the environment. In economically important towns, flood protection will be provided as a priority, and in the Zila and Upazila levels, phased implementation of reasonable flood protection facilities will be introduced. Sustainable improvements will be targeted in operational efficiency and service delivery, and affordable and financially sustainable services will be offered to all levels of society, with particular emphasis on the poor and disadvantaged. The programmes developed under the plan are as follows: rural and urban Arsenic mitigation, large and small town water supply and distribution systems, rural water supply and distribution systems, large and small town sanitation and sewerage systems, rural sanitation, large and small town flood protection, and large and small town storm-water drainage.

Major Cities: One of the major challenges is to address the development requirements of the urban sector. As in the Towns, the main aims for these major cities (Dhaka, Chittagong, Khulna and Rajshahi) are, to the extent feasible and affordable, to satisfy increasing demands for safe drinking water and sanitation and provide adequate flood protection and storm water drainage. As in other urban and peri-urban areas, measures will be taken up with particular emphasis on the poor and disadvantaged. The programmes developed under the plan are: bulk water supply and distribution systems for Dhaka, Chittagong, Khulna and Rajshahi, sanitation and sewerage systems for the four cities as above, flood protection for the four cities, and storm-water drainage also for the four cities.

Disaster Management: Disaster management involves prevention and mitigation measures, preparedness plans and related warning systems, emergency response measures and post-disaster reconstruction and rehabilitation, and is recognised as a necessary element of overall water management. Whilst some people will always remain at risk, the main aims are to provide the means by which, through a combination of structural and non-structural measures, adequate warnings are given, people can survive with most of their assets intact, and can rebuild their lives thereafter. The programmes proposed under the disaster management are: cyclone shelters and killas, flood proofing in the charlands and haor basin, and for national, regional and key feeder roads, and railways, and supplementary irrigation and drought proofing of rural water supplies.

Agriculture and Water Management: The overall agricultural policy objective is to expand and diversify agricultural production and to maintain food security, especially with regard to sustaining self-sufficiency in rice. The water sector has an important role to play by removing constraints that may be caused by either shortage or excess of water. This will involve promoting continued expansion of minor irrigation, water conservation for multi-purpose use, rationalization of the many existing public flood control, drainage and irrigation schemes, a limited number of new irrigation schemes where needed and feasible, and improved coastal protection works, including mangrove afforestation on the foreshore as well as in the country's upland catchments. In undertaking these works, the potential impacts of climate change and sea-level rise will be factored in. The programmes developed under the plan are: promotion of expanded minor irrigation, improved performance of existing public surface water irrigation schemes, new public surface water and deep tube well irrigation schemes, improved water management at community and local government levels, rationalization of existing FCD infrastructure, and land reclamation, coastal protection and afforestation.

Natural Environment and Aquatic Resources: The key objectives of this cluster are: to ensure provision of clean water for multipurpose uses; to restore and maintain fish habitats; to ensure provision of water for sustainable use; to preserve key features of wetlands; to protect the aquatic environment in the future; and to prevent degradation of upland watersheds. Implicit in these objectives are the institutionalization of EIA and environmental management procedures. The programmes developed under the plan are as follows: national pollution control plan, national clean-up of existing industrial pollution, national water quality monitoring, national fisheries master plan, national fish pass programme, unspecified regional programmes, improved water management in the haor basins of the north east region, environmentally critical areas and integrated wetland management, improved water management and salinity control in the Sundarbans, and public awareness raising and empowerment in respect of environmental issues.

5.7 Synergies and Gaps

The NWMP suggested some programmes to facilitate irrigation, such as: Supplementary irrigation and drought proofing of rural water supplies; promotion of expanded minor irrigation and improved on-farm water management; improved performance of existing public surface water irrigation schemes; new public surface water irrigation schemes etc.

The NWMP is an integrated water resource development plan prepared in a comprehensive manner and with a multi-sectoral approach. This plan includes list of programmes for the identified hydrological regions. However, spatial dimension and associated economic impacts are missing. Linkage with other Master Plans is also missing. If the strategies had been indicated spatially using either structural or strategic plans then it would have been easier for the water resources planners to grasp an idea on the existing ongoing as well as future projects; moreover it would have given the policymakers an idea about the future direction of regional growth. Regional programmes mentioned in the NWMP should have been supported by action plans.

During the planning phase of NWMP, it was decided at policy level that prioritisation of projects/ investments were prerogatives of the politicians, and would be decided at that level first and then the action plan would follow. Before the Government could complete the approval process of the NWMP, a new Government took office (2001), and the plan took three years to get approved. Nevertheless, the development partners used NWMP as a guidance of new projects as well as BWDB and other water agencies used it as guidance for new projects.

A strong monitoring system and regular surveillance is necessary, which is not suggested in the plan. WARPO developed a monitoring system initially, but it became ineffective due to lack of interest of the-then Government and lack of able leadership in WARPO. Some development partners especially the Dutch-supported tried to push ahead through Twining Mission, but it failed. Later, the initiatives taken by the Netherlands embassy could not also succeed.

The planning period of NWMP was up to the year 2025 (25 years from its concept year 2000); which is, at present, is only about 10 years from now, after which, it will become redundant and will need to be updated.

In accordance with the provision of NWMP, the DPPs of all water sector projects were to get clearance by WARPO before approval by the Planning Commission. Unfortunately, except some BWDB and LGED projects, no other agencies followed or adopted the approval process. The inherent weakness in the organizational structure is equally responsible for this debacle.

Observation: The NWMP is very a comprehensive and integrated planning document for all sectors of the country. However, as it is only a framework plan, only programs were developed. The implementing agencies were supposed to develop their own projects based on the programs, but because of the lack of clear guidance they could not develop those. In NWMP, the implementation programs were not prioritized; the responsibility for doing that was given to the implementing agencies, which also they could not do. NWMP provided a short term firm plan containing projects covering a period five years from 2000 to 2005. Although the plan was completed in 2001, due to a lengthy approval process, it was finally completed in 2004. By the time it was approved, the plan was already 3 years behind schedule and the momentum was lost.

The NWMP was to be reviewed and updated every five years by WARPO, but because of high level of inefficiency and poor professional resources available in WARPO, that was never done, even for a single time in last twelve years. This only indicates the incapability of WARPO as a coordinating agency for such a large water management plan. If a plan of NWMP's stature was to be materialised, a much better and efficient organizational set up would be necessary than what WARPO has/had. Qualified and experienced professionals staff should be recruited offering competitive wages, and the digital know-how must be introduced at all levels of work in the office. The age-old concept of typical setup would not achieve any results. It can be safely said that had WARPO updated the NWMP, and some of the planned projects could be implemented, the water resources planning of the country would have advanced much during the last one decade. Now the status of NWMP has become uncertain, as a new decree is there for WARPO to prepare a new plan, namely, National Water Resources Plan (NWRP).

6. Organizations under Water Resources Sector

Water resource is the key to any country's sustainable development. The National Sustainable Development Strategy (NSDS), published by Government in 2013, (GED, 2010 – 2021), identifies the following *five priority development sectors* for the country: *Agriculture*, *Industry*, *Energy*, *Transport* and *Human Resource Development* (NSDS, p. xii and further). Of these, water resource is particularly vital for the *Agriculture* sector, which includes the crop sector, livestock, fisheries and forestry sub-sectors. Agriculture provides employment to approximately 70% of the population and contributes some 19.5% to the National GDP (2004 – 2010, NSDS, 2013). Fish and fishery products are the country's third largest export commodity contributing 5.1% of its exchange earnings (FAO, 2011), 4.91% of its GDP and provides 63% of the national animal protein consumption (DoF, 2003).

Water resource is also important for the *Transport* sector, although less so than for Agriculture. According to Mishra et al (2012), the Inland Water Transport (IWT) sub-sector, supports the livelihoods of some 6.4 million people and contributes 30% of overall freight transport output and 20% of passenger travel. A 2007 World Bank study (2007, quoted in Mishra, D. K. et al, 2012), revealed that IWT has proved more accessible and cheaper than roads and railways and the poor people use the mode more. The same study shows that 12.3% of the rural population or 50% of all rural households have access to water transport. The IWT sector is growing rapidly, with cargo traffic increasing from 20 to 30 million tons annually from 1994 to 2005. *Navigability of the waterways* and *port development* are key issues for the IWT sub-sector.

With the background as mentioned above, over 40 different agencies and organizations are involved in the water development and water management sector. However, the main functions of some of the major organizations are briefly is being described in this report. They are Bangladesh Water Development Board (BWDB), Water Resources Planning Organization (WARPO), Department of Bangladesh Haor and Wetland Development

(DBHWD), Local Government Engineering Department (LGED), Bangladesh Agriculture Development Corporation (BADC), Barind Multipurpose Development Authority (BMDA), and three Water Supply and Sewerage Authority (WASA) at Dhaka, Chittagong and Khulna. Another agency naming Bangladesh Inland Water Transport Authority (BIWTA), though under the transport sector, is undeniably related to the water resources sector; the NWMP mentions the agency in many WR development projects. Two other Trust organizations running on their own money, namely, Institute of Water Modelling (IWM) and Centre for Environmental and Geographic Information Services (CEGIS) have also become integral part of the water resources sector for last two decades due to their dedicated and invaluable services rendered to the sector.

However, the Ministry of Water Resources (MoWR), previously known as the Ministry of Irrigation, Water Development and Flood Control, is the apex body for development and management of whole water resources in the country. It formulates policies, plans, strategies, guidelines, instructions and acts, rules, regulations, etc. relating to the development and management of water resources. The Joint Rivers Commission (JRC) is directly under the ministry; the commission is responsible for data on Trans-Boundary Rivers (57 identified border rivers, 54 with India and 3 with Myanmar); much of which is considered as restricted information. Another autonomous organization, namely the River Research Institute (RRI), is also under the ministry's direct jurisdiction. RRI provides very essential support services for sustainable planning, design and management of water resources development projects. It grew out of BWDB's Hydraulic Research Laboratory (established in 1948) and separated from BWDB on 20 August 1991.

By early 1980s', the focus of water resources planning was shifted from mono-sector (agriculture) to multi-sector approach and Master Plan Organization (MPO) was established under the Ministry (then known as M/o Irrigation, Water Development and Flood Control). The MPO prepared the National Water Plan (NWP) Phase I in 1986, and Phase II in 1991, focusing on the assessment of water resources and future demand by different users. The NWP assembled a substantial amount of information, developed a range of planning models and programs, many of which were adopted by the government and endorsed by the donors. In 1991, MPO was renamed as the Water Resources Planning Organization (WARPO). One of its main mandates was to evolve national policies and strategies for utilization and conservation of water resources, such as: Water Resources Planning Act, 1992; National Water Policy, 1999; Coastal Zone Policy, 2005; National Water Management Plan, 2004; National Water Resources Council (NWRC); the Executive Committee of the National Water Resources Council (ECNWRC), etc. WARPO's objectives were to upgrade the National Water Plan with an inter-sectoral focus and an interdisciplinary approach, particularly emphasizing environmental issues.

However, the Bangladesh Water Development Board (BWDB), which came into being in 1959 as the Water Wing of the erstwhile East Pakistan Water and Power Development Authority, remained the most important and major organization under the ministry. By far, BWDB carried out the highest number of water resources development projects in the country since its inception. Unfortunately, over the years, the organization has lost much of its credibility due to various reasons, discussed elsewhere in this report. In the year 2000, the Government proclaimed BWDB Act 2000 to streamline effective operation and maintenance of FCDI projects, bringing all the activities of BWDB under legal footing. The act outlined the organizational structure of BWDB along with the mandate. The Act has created an environment for reforming BWDB. Under the changed circumstances, the mission, the vision, the goals, the objectives, the targets and the action plan of the organization needed to be defined clearly. The aim of the reform is:

National River Conservation Commission Act, 2013 was approved by the parliament in 2013 and made effective with the aim of preventing illegal occupation of rivers, pollution of water and environment, river pollution by industrial wastes, construction of illegal structures and various irregularities, restoring natural flows of rivers, conserving rivers in proper ways, keeping them navigable and ensuring multipurpose use of rivers for socio-economic development. The commission works as a recommending body under the Shipping Ministry. The Commission (NRCC) started working in 2014 with an aim to save the rivers from pollution and encroachment. The organizations involved with water resources directly or indirectly are described briefly in the following sections.

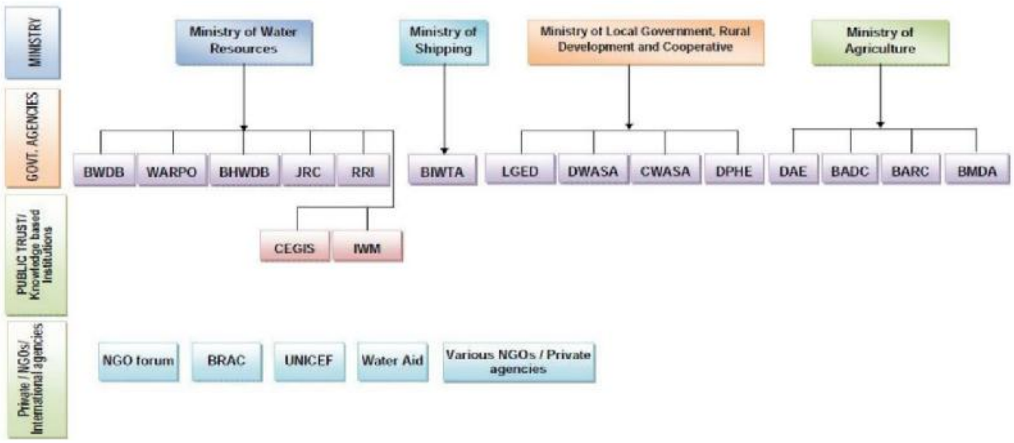


Figure 6.1: Post Independence Institutional Development of Water Resources Planning in Bangladesh

Source: Ministry of Water Resources

6.1 Bangladesh Water Development Board

Bangladesh Water Development Board (BWDB), which came into force in 1959 as the Water Wing of the former East Pakistan Water and Power Development Authority, restructured in 1972 as a fully autonomous organization. The Board consists of 9 zones, 22 circles, 78 divisions and 201 sub-divisions at the field level. According to the BWDB Act 2000, a 13-member council was constituted with the Minister for Water Resources as its Chairman to take policy decisions for administering the board. The board was also reconstituted creating new posts of one Director General and five Additional Director Generals to run the administrative and other assigned functions of the board. These are administration, finance, O&M, planning and implementation. The DG's office and the five wings form the core of the headquarters of the BWDB. At this stage, it is worthwhile to look at functions of the two relevant segments of BWDB: Planning, and Operation & Maintenance (O&M).

The activities of the BWDB Planning are as follows:

- Providing inputs and technical reviews for the preparation of National Level Perspective and the Five Year Development Plans.
- Micro planning for water resources development consistent with the National Water Policy and within context of the National Water Management Plan (NWMP).
- Hydrological studies, data collection, management and research.
- Undertaking activities for formulation and preparation of planning documentation for BWDB projects
- Maintaining updated management information related to planning of water sector development.
- Supporting WARPO and other water sector agencies in the development of efficient water resources management and utilisation of plans and updating various Guidelines on water management.

The activities under the BWDB O&M are as follows:

- Preparing and updating of inventory of completed projects containing all basic project information.
- Operation and maintenance of completed projects over 5000ha as outlined in the NWPO.
- Providing management guidelines and necessary assistance to local and community organizations and the local governments for O&M of projects with command area below 5000 ha
- Rehabilitation of projects under GOB funding and as directed by the Board from time to time
- Transfer of rehabilitated/operating projects of 1000 ha or below to the local governments
- Water management activities as indicated in the NWMP
- Cost recovery, command area development and matters related to participatory water management
- Preventive work to forestall damage to water infrastructure due to natural disasters, damage assessment and emergency repairs following natural disasters

6.2 Water Resources Planning Organization (WARPO)

The Water Resources Planning Organization (WARPO) is an apex organization under the Ministry of Water Resources, dealing with nationwide water resources planning. As mentioned earlier, the Master Plan Organization (MPO) was renamed as WARPO in 1991. Another agency, Flood Plan Coordination Organization (FPCO) was created in 1989 to coordinate Flood Action Plan (FAP) activities, but later merged with WARPO in January 1996. WARPO is a multi-disciplinary organization having seven technical and one administrative section covering Agriculture, Economics, Environment, Engineering, Forest & Fisheries, Water Resources, Information Technology, and Monitoring & Evaluation. A Governing body chaired by the Minister, Ministry of Water Resources, is conducting the management of WARPO. The body consists of 10 members. There is an Executive committee, which is composed of Director General and two directors of WARPO. The committee will advise and assist the Governing Body and is responsible for the implementation of the decision of Governing Body. A Technical Committee, headed by the Member, Agriculture, Water Resources and Rural Institution Division of Planning Commission, was formed in June 1994, and consists of five members to advise WARPO on technical coordination among water-related agencies.

Director General, WARPO is Member-Secretary to both of these setups and he is assisted by two Directors who are responsible for carrying out the day to day activities. The Chief Scientific Officers are in charge of overseeing the technical sections under Principal Scientific Officers (PSO) and other professionals.

Over the years WARPO has prepared two strategies, i.e. NWMP Development Strategy 2001 and the Coastal Development Strategy 2005. It also prepared two guidelines, i.e. the Guidelines for Environmental Assessment of Water Management (Flood Control, Drainage and Irrigation) Projects 2005 and the Guidelines for Participatory Water Management 2000.

WARPO has prepared the National Water Management Plan in 2001 which was approved in 2004. Now, it will have to prepare the National Water Resources Plan as provided in the National Water Act 2013.

6.3 Department of Bangladesh Haor and Wetland Development (DBHWD)

Bangladesh Haor and Wetland Development Board (BHWDB) was established under the Ministry of Water Resources by a Presidential order on 11th September 2000 but under the *Bangladesh Haor & Water Bodies Development Board Act 2014*. The board was renamed as Department of Bangladesh Haor and Wetland Development (DBHWD) and has been provided the status of a Directorate attached to the Ministry of Water Resources. The Department is governed by a Board consisting of 13 members headed by the Prime Minister. It is the highest authority for approval of policy directives for the DBHWD. There is a 10-member Executive Committee chaired by the Minister, Ministry of Water Resources. This Executive Committee provides assistance to the Board. For operational purpose, the BHWDB is headed by the Director General. The DG is supported by two Directors: Director (Finance & Admin) and Director (Wetlands) who in turn assisted by three Deputy Directors: Deputy Director (Engineering), Deputy Director (Agriculture & Fisheries) and Deputy Director (Land & Environment) and two Deputy Directors located at regional offices at Kishoreganj and Sunamganj. In addition to preparing Master Plan for Haor Area in 2012, the following activities are earmarked for the department.

- Coordinate the integrated development of the haors and wetlands of Bangladesh among the ministries, agencies and local government bodies;
- Formulate projects related to the development of haors and wetlands and implement projects through local government bodies and other agencies;
- Examine and co-ordinate different projects to be implemented by different ministries and agencies and provide proper advice to the implementing agencies.

6.4 Bangladesh Agricultural Development Corporation (BADC)

Bangladesh Agricultural Development Corporation (BADC) the successor of the East Pakistan Agricultural Development Corporation, established under an Ordinance in 1961. In 1975, BADC was renamed as the Bangladesh Agricultural Inputs Supply and Services Corporation (BAISSC) to distinguish the functions of the corporation from other development agencies of the Government in the agricultural sector. But for all practical purposes the Government restored the status quo and BAISSC was renamed as BADC under an Ordinance in 1976. Based in Dhaka city, BADC, a semi-autonomous corporate body under the Ministry of Agriculture, serves to the whole of Bangladesh and has a nationwide network of outlying field offices down to the upazila level and at some places even below that level. The main objective is to increase agricultural production in Bangladesh.

The general direction and administration of the corporation and all of its affairs are vested in a Board of Directors headed by the Chairman. The operational set-up of the Corporation comprises six wings. These are: Administration, Irrigation, Seed, Supply, Planning, and Finance. The administrative wing is under the direct control of the Chairman, and each wing is headed by the concerned Member-Director.

Three categories of functions are assigned to BADC under the 1961 Ordinance. The mandatory or primary functions are: to make suitable arrangements throughout Bangladesh on a commercial basis, for the procurement, transport, storage and distribution to agriculturists of essential supplies such as seed, fertilizers, plant protection equipment, pesticides, and agricultural machinery and implements; to promote the setting up of co-operative societies with a view to handing over to them its supply functions in accordance with phased programmes; to encourage the development of co-operative societies in other spheres in which the Corporation is interested; to take over and manage seed multiplication and livestock breeding farms and fruit nurseries; and to assist, encourage and promote the manufacture of improved agricultural machinery and implements.

The optional functions in relation to mandatory responsibilities among others are to give loans in kind; to assist, encourage and promote the establishment of industries for the processing of agricultural produce, formulating or manufacturing of insecticides, pesticides, fungicides etc.; and to organise the supply, maintenance and operation of lift-pumps and tube-wells, and set up light workshops for running repairs. Professionals from different disciplines such as engineering, agriculture, economics, management etc. work together in BADC.

More than 70% of the irrigated cropland is being irrigated by equipment provided by BADC. It has enhanced the distribution of fertilisers from 50 thousand to 2.2 million m tons. In the seed sector, the production of improved seeds through seed multiplication farms and contract growers, and procurement, processing, and distribution of seeds have been continued. But due to the privatization of many activities of the irrigation, fertiliser and seed sectors, the role of BADC has been reduced substantially in recent years.

6.5 Local Government Engineering Department (LGED)

Local Government Engineering Department (LGED) is one of the largest public sector organizations entrusted for planning and implementation of local level rural urban and small scale water resources infrastructure development programs. LGED works closely with the local stakeholders to ensure people's participation and bottom–up planning in all stages of project implementation cycle. The core activities of LGED can be broadly categorized to include: rural infrastructure development, urban infrastructure development, and small scale water resources (SSWR) development. The broad objectives of LGED's development activities are to improve the socio-economic condition of the country through supply of infrastructure at local level and capacity building of the stakeholders. LGED promotes labour-based technology to create employment opportunity at local level and uses local materials in construction and maintenance to optimize the project implementation cost with preserving the desired quality.

LGED works in a wide range of diversified programs like construction of roads, bridges/ culverts and markets to social mobilization, empowerment and environmental protection. Its organizational background can be traced back to early 1960s' when implementation of works program (WP) comprising Rural Works Program (RWP), Thana Irrigation program (TIP) and Thana Technical Development Committee (TTDC) was started. A ''Cell'' was established in the Local Government Division (LGD) under the Ministry of Local Government, Rural Development and Cooperative (MLGRD&C) in 1970s. To administer WP nationwide, the Works Program Wing (WPW) was created in 1982 under the Development Budget. It was reformed into the Local Government Engineering Bureau (LGEB) under Revenue Budget of the Government in October, 1984. LGEB was upgraded as the Local Government Engineering Department (LGED) in August, 1992.

Some small schemes, mostly on surface water based irrigation, were implemented by the Thana Irrigation Program (TIP) under the Works Program of the government during 1960s. LGED implemented 60 SSWR schemes under the Rural Employment Sector Program during 1986 to 1996. Based on experience of these earlier water resources development activities, LGED was entrusted to implement the first program on small scale water resources development, the SSWRDSP (1995-2003) assisted by the ADB in 37 western districts of the country. The program was designed to ensure participation of the beneficiaries and other local stakeholders in the process of subproject implementation and subsequent O&M by establishing beneficiaries' Participatory Water Management Cooperative Association (WMCA). In the meantime, the NWP was formulated which defined the role of Local Government Institutions (LGI) in water resources development and gave a mandate to implement flood control, drainage and irrigation (FCDI) subprojects with a benefited area of up to 1000 ha.

6.6 Department of Public Health Engineering (DPHE)

Department of Public Health Engineering (DPHE) is the national lead agency for provision of drinking water supply and waste management in the country excepting Dhaka, Narayanganj and Chittagong cities, where WASAs operate. With the challenges generated by the discovery of arsenic in incremental areas since its first detection in 1993, DPHE with its development partners is trying to ameliorate the sufferings caused by the lack of safe water. Alternative options for safe water supply are being catered in worse affected areas. Similarly, for excreta and other waste management, DPHE is implementing different projects to achieve an improved environment.

DPHE provides advisory service to the Government in framing policy and action plans for Water Supply and Sanitation. It also provides support to the local government institutions (LGIs) in the development and O&M of the water and sanitation facilities.

6.7 Dhaka Water Supply and Sewerage Authority (DWASA)

Dhaka Water Supply and Sewerage Authority (DWASA) was established in the year 1963 as an independent organization. In 1989, the drainage system of Dhaka city was also handed over to DWASA from DPHE. Again, in the year 1990, Water, Drainage & Sanitation service of Narayanganj city was handed over to DWASA. Based on the tremendous geographical expansion and population growth over the last two decades, DWASA's activities has been reorganized by Dhaka WASA Act, 1996 and according to this act, DWASA it is operating as a service oriented commercial organization. Now, the jurisdiction of Dhaka WASA is more than 360 Sq. km and the population is about 12.5 million. The major responsibilities and functions of DWASA are:

- Construction, operation, improvement and maintenance of the necessary infrastructure for collecting, treating, preserving and supplying potable water to the public, industries and commercial concerns;
- Construction, operation, improvement and maintenance of the necessary infrastructure for collecting, treating and disposing domestic sewerage; and
- Construction, operation, improvement and maintenance of the necessary infrastructure for drainage facilities of the City.

In Dhaka city 87% water supply is abstracted from groundwater resources and the remaining from surface water resources. Due to over exploitation the groundwater table is lowering down very rapidly (2-3 m per year in some places). Recently DWASA has taken the strategy to decrease the dependency on groundwater by taking many surface water related projects. The surrounding river water is being polluted by industrial and domestic effluent discharge without or after little treatment, DWASA decided to transport the water from Padma and Jamuna River, where the water quality and quantity is still quite satisfactory, to meet the growing demand of water in Dhaka city.

At present the service area of DWASA extended to Mirpur and Uttara in the North and to Narayanganj in the South. For better operation, maintenance and customer care, the total service area of DWASA is divided into 11 geographic zones, which includes 10 in Dhaka City and 1 in Narayanganj.

6.8 Chittagong Water Supply and Sewerage Authority (CWASA)

Chittagong Water Supply and Sewerage Authority (CWASA) was established in 1963, with the following specific objectives:

- Construction, improvement, expansion, operation and maintenance of necessary infrastructure for water supply in Chittagong metropolitan area for domestic, industrial and commercial purpose;
- Construction, operation and maintenance of sewerage system in Chittagong metropolitan area;
- Construction, operation and maintenance of drainage facilities to carry rain, flood and surface water;
- Solid waste management.

6.9 Khulna Water Supply and Sewerage Authority (KWASA)

Khulna Water Supply and Sewerage Authority (KWASA) was established in 2008 as an independent organization and separated from Khulna City Corporation. KWASA is committed to ensure service to all customers through the supply of a sufficient amount of potable water and proper sewerage solutions, implement efficient operation & maintenance, research, effective planning and human resource (HR) development. Its vision is to be the one of the premier agencies in the water and sewerage sector in Bangladesh ensuring safe and sustainable water supply and environment friendly sewerage management for Khulna City to the satisfaction of its customers. One of its aims is to reduce dependency on groundwater and use more surface water wherever possible.

6.10 Bangladesh Inland Water Transport Authority (BIWTA)

Bangladesh Inland Water Transport Authority (BIWTA), the erstwhile East Pakistan Inland Water Transport Authority, was established in 1958 and constituted of three members. BIWTA is mainly responsible for development, maintenance and operation of inland water transport and of inland waterways. BIWTA performs statutory functions of development, maintenance and regulatory nature, which are described below:

- Carry out river conservancy works including river training works for navigational purposes and for provision of aids to navigation including marks, buoys, lights and semaphore signals.
- Disseminate navigational and meteorological information including publication of river charts;
- Provide pilotage and hydrographic survey services.
- Draw up programmers of dredging requirements and priorities for efficient maintenance of existing navigable waterways
- Develop, maintain and operate inland river ports, landing/ferry ghats and terminal facilities
- Carry out removal of wrecks and obstruction in inland navigable waterways.
- Conduct traffic surveys to establish passenger and cargo requirements on the main rivers, feeders and creek routes.
- Develop rural water transport by progressing of schemes for modernising and mechanizing country craft.
- Ensure co-ordination of Inland Water Transport with other forms of transport, with major sea ports, and with trade and agricultural interests for the optimum utilisation of the available transport capacity.
- Conduct research in matters relating to Inland Water Transport including development of craft design technique of towage, landing and terminal facilities, and port installations
- Arrange programmes of technical training for Inland Water Transport personnel
- Maintain liaison with the shipyard and ship repair industry to meet the requirements of the Inland Water Transport fleet repairs and new constructions.
- Maintain liaison with the Government and facilitate import of repair materials for the Inland Water Transport Industry.
- Fixation of maximum and minimum fares and freight rates for Inland Water Transport on behalf of the Govt.
- Approve time tables for passenger launch services
- Act as the Competent Authority of Bangladesh for the protocol on Inland Water Transit and Trade, looking after the use of waterways of Bangladesh on behalf of the Govt. for the purpose of trade and transit between Bangladesh and India as provided in the Protocol.

Bangladesh has about 24,000 km. of rivers, streams and canals that covers about 7% of the country's surface. Most part of the country is linked by a complex network of waterways which reaches its extensive size in the monsoon period. Out of 24,000 km. of rivers, streams and canals, only about 5,968 km. is navigable by mechanized vessels during monsoon period which shrinks to about 3,865 km during dry period. There are 88 classified IWT routes in Bangladesh.

BIWTA has established 21 inland river ports and 380 landing stations throughout the country. Moreover, according to BIWTA, in 2013-14, around 87.40 million of passengers and 35.18 million tons of cargo were conveyed throughout the nine major river ports. A large fleet of about 10,000 inland vessels are engaged in the carriage of goods and passengers. Besides there are approximately 750,000 country boats powered by the pump engines operating mainly in the rural waterways. To maintain the navigability of the routes, dredging is necessary in Bangladesh. There are 21 dredger fleet in BIWTA and the dredging capacity of those are 110 lakh m^3 per year.

6.11 Barind Multipurpose Development Authority (BMDA)

In 1985 the Government approved a project named Barind Integrated Area Development Project under the Bangladesh Agricultural Development Corporation. In 1990 the project was declared complete using only 26% of the fund allocated. On completion of the project a review was conducted and to speed up the development project implementation of the Barind area a separate authority was created under the name of Barind Multipurpose Development Authority (BMDA) on 15th January 1992 under the Ministry of Agriculture. The authority has so far implemented 23 (Twenty-three) development projects. The priorities of the Barind Area particularly concerning the development of Agriculture include:

- Augmentation of surface water resources and its use
- Increasing irrigation facilities by using groundwater through Deep Tube Wells
- Formulate and implement command area development project for creating water supply system for irrigation and development of irrigation
- Insure electrification of irrigation equipment and agro-based industries in the area
- Re-excavation of Ponds/Khal for pisci-culture (fish farming) development and for Irrigation
- Afforestation to achieve environmental and ecological balance
- Improving road communication by construction/Re-construction of feeder Roads
- Crop diversification by using Deep Tube wells, Shallow Tube wells and other pumps

BMDA carried out installation of 1,516 deep tube wells and electrification of 1,764 deep tube wells and construction of 3,055 irrigation canals; 45,600 hectares of land were brought under regulated irrigation over the last three years. Another 1,525 obsolete deep tube wells of BADC were made operational for irrigation. The re-excavation of 696 km of canals, re-excavation of 465 dead ponds and preservation of surface water through construction of 419 cross dams, brought 30,000 hectares of land under supplementary irrigation. 1,650 MT of paddy seeds were produced, preserved and distributed among the farmers at a fair price and 15,000 farmers were provided with training. 9 lakh fruit trees and medicinal saplings were planted in the Barind area.

However, use of tubewell technology by BMDA seemed to have some adverse effects on water resources, as a result of over-exploitation of groundwater. BMDA adopted certain spacing between tubewells after a study recommended that the haphazard construction of tubewells may result in lowering the groundwater to a level below than it can recharge. The report also recommended pumping water by LLP during the monsoon months, so that the groundwater reservoir can be recharged during the period. One additional problem is that some private tubewells are installed in an unplanned way through political influence, which should be stopped. If the abstraction rate is higher than the recharge, groundwater mining may occur.

Two other organizations, namely Institute of Water Modelling (IWM) and CEGIS were formed under the Ministry of water resources as "Trust" under the Government Trust Act. These two organizations have been intensely involved in very important projects in the water sector, with their advanced technical knowhow (mathematical modelling, GIS and Remote Sensing), and earned name and fame in Bangladesh and abroad. At present data base for many vital projects of the water sector are stored and preserved in these two institutions. The activities of the two are briefly described below.

6.12 Institute of Water Modelling (IWM)

During the preparation of the National Water Plan under MPO in the early 1980s', it was realised that sophisticated analysis tools like mathematical modelling would be needed to prepare a multi-sectoral master plan. Under the financial assistance of World Bank and UNDP, the Government initiated the mathematical modelling technology in 1986 under the Surface Water Simulation Modelling Programme (SWSMP). During the second phase of the simulation program, the organization was named Surface Water Modelling Centre, which was late renamed as Institution of Water Modelling (IWM) and made as a Trust under the Trusts Act, 1882 to institutionalise SWMC.

IWM provides services in the field of Water Modelling, Computational Hydraulics & Allied Sciences for improved integrated Water Resources Management. The applications of IWM modelling tools cover a wide range of water-related areas such as flood control, flood forecasting, irrigation and drainage, river morphology, salinity and sediment transport, coastal hydraulics, port, coast and estuary management, EIA, bridge hydraulics and related infrastructure. It provides services on the above fields on a cost recovery basis in enhancing the quality of planning and implementation. The organization can now boast of becoming a world-class institution in the field of water modelling, computational hydraulics and allied sciences.

IWM is governed by a Board of Trustees with top level representatives from national authorities and organizations : Ministry of Water Resources; Ministry of Planning; Ministry of Finance; Bangladesh Water Development Board (BWDB); Water Resources Planning Organization (WARPO); Bangladesh University of Engineering and Technology (BUET); Roads and Highways Department, Local Government Engineering Department, NGO, Institute of Engineers Bangladesh, Private Commercial Bank; DHI Water & Environment and IWM itself.

During the last two decades, IWM has been working with a varied range of national and international projects of various disciplines, such as water resources, environment, forest, navigation, transport sectors. The clientele includes BWDB, WARPO, LGED, RHD, DWASA, CWASA, BBA, BMDA, BIWTA, etc. and scores of national and international consultants. Some of the completed projects where IWM was involved were: Updating of flood hydrology study, JICA baseline study for Dhaka, Flood Forecast Modelling for FAP-10, Modelling support to NWMP, Options for Ganges Dependent Area, DWASA Master Plan, Fourth Water Supply Project (DWASA), GW modelling for 148 municipalities under DPHE, Command Area Development (MDIP and PIRDP), Bangabandhu Jamuna Bridge, KJDRP, Comprehensive Disaster Management Program (CDMP), Sundarban forest Hydraulic study, River Bank Improvement Project, etc.

One of the main strengths of IWM is a core team of highly experienced professional staff, who are working dedicatedly to leave a mark of quality in their job assignments. There is a set program for human resources development (HRD), under which staff are continuously trained and motivated to improve their knowledge and skill to endure in this competitive world.

6.13 Center for Environmental & Geographic Information Services (CEGIS)

Center for Environmental and Geographic Information Services (CEGIS), a Public Trust formed by a Cabinet decision in 2002, is functioning under the aegis of the Ministry of Water Resources. It provides intellectual services for natural resources and disaster management using GIS, RS and database technology for integrated environmental and social analysis. Its' services and projects include IEE, EIA, SIA, RAP, analytical framework for Integrated Water Resources Management (IWRM), etc. The working domain of CEGIS span over Resource Management Planning (Natural and Intellectual), System Development, Capacity Building and Research activities.

CEGIS, in total, has fourteen divisions of which eleven are discipline-specific and functioning through highly qualified, experienced and multitasking professionals of scientific, technical and socio-economic expertise. Each of these divisions works both independently as well as collectively in the form of multidisciplinary team, on the projects.

7. Achievements in Water Resource Development

Over the years, Bangladesh Water Development Board (BWDB) principally carried out the water resources development and management in the country. During the last 60 years, it has implemented nearly 800 projects for flood control, drainage, irrigation, river training and town protection projects. These projects had implemented to provide flood-free land for agriculture, and better safety to human lives, livestock, settlement, industry and infrastructure.

BWDB have brought about 6.3 million ha under flood protection and 1.6 million ha under irrigation facilities in 2014-15. The summary of infrastructure under FCDI facilities are shown in Table 7.1.

Table 7.1: Summary of Water resources development projects by BWDB (1954-2015)

Item	Quantity
Completed projects	790 nos
FCDI project coverage area	6.3 million ha
Irrigated area (120 Irrigation projects)	1.6 million ha
Barrages (Teesta, Monu, Buri Teesta, Tangon)	4 nos
Land reclamation	1 020 sq km
Town Protection project	22 nos
Length of Completed Embankment	11 393 km
Length of irrigation canal	5 337 km
Hydraulic Structure	14 744 nos
No of Pump House	20 nos
Closure	1 379 nos
Bridge/ Culvert	5 643 nos
Rubber Dam	5 nos
River Dredging and Excavation	280 km
Road (pucca and kacha)	1 070 km
Drainage canal	4425 km

Under the BDP 2100 Baseline study of Water Resources, an analysis carried out to find out the types of facilities provided by the completed projects and the projects subdivided into several categories. The project types FCD and CFCD are flood control and drainage projects (CFCD means Coastal FCD), whereas FCDI and CFCDI are flood control, drainage and irrigation projects. Project types DR and DI are drainage only and drainage & irrigation projects respectively and have not been counted as Flood Control (FC) projects. SFCD and SFCDI projects stand for submersible polders or flood control and drainage projects in haor areas. The completed projects have also been analysed according to its coverage size into four categories: small projects which cover less than 1000 ha, medium projects which cover an area of 1000-5000 ha, and large projects having implementing areas of 5000-15000 ha, and lastly very large projects having an area above 15000 ha. The Table 7.2 shows the distribution of BWDB projects in terms of coverage area.

Table 7.2: Classification of Projects (type & size) implemented by BWDB

Type of Projects	Projects Size (1000 ha) Small 0-1	Medium 1 - 5	Large 5 - 15	Very large >15	Total
Irrigation (IRR)					
i) Number of Projects	70	20	7	11	108
ii) Area in ha	24	44	54	550	672
Drainage (DR)					
i) Number of Projects	55	59	11	8	133
ii) Area in ha	31	140	78	629	878
Drainage and Irrigation (DI)					
i) Number of Projects	1	9	1	3	14
ii) Area in ha	0	21	7	406	434
Flood Control and Drainage (FCD)					
i) Number of Projects	9	49	35	31	145
ii) Area in ha	18	131	312	1402	1863
Flood Control, Drainage and Irrigation (FCDI)					
i) Number of Projects	9	13	14	24	60
ii) Area in ha	5	37	120	2048	2209
Submersible Flood Control and Drainage (SFCD)					
i) Number of Projects	2	12	5	6	25
ii) Area in ha	1	43	30	123	198
Submersible Flood Control Drainage and Irrigation (SFCDI)					
i) Number of Projects		2			2
ii) Area in ha		7			7
Coastal Flood Control Drainage (CFCD)					
i) Number of Projects	17	42	27	17	103
ii) Area in ha	10	131	258	601	1000
Coastal FCD and Irrigation (CFCDI)					
i) Number of Projects	1	3	2		6
ii) Area in ha	1	7	20		28
Shrimp Culture Polder (SCP)					
i) Number of Projects		2	3		5
ii) Area in ha		7	26		32
Total					
i) Number of Projects	185	211	105	100	601
ii) Area in ha	89	568	905	5760	7322
Percentage-wise Distribution					
i) Number of Projects	30.78%	35.11%	17.47%	16.64%	100%
ii) Area in ha	1.22%	7.75%	12.36%	78.67%	100%
Feasibility Study (FS)					61
Town Protection Projects – (TP)					59
Protection Projects (P)					49

Source: BDP 2100 Baseline report on Water Resources

Among the completed projects, the Flood control and Drainage (FCD) projects are predominant. Around 145 projects are implemented which is under FCD projects. Another predominant project type is Drainage (DR); which have a number of around 130 projects. Moreover, a large number of projects are completed by BWDB for, Irrigation (120 projects), Submersible Flood control, Drainage and Irrigation (2 projects), Coastal Flood Control, Drainage and Irrigation (6 projects), Shrimp Culture Polder (5 projects), Town Protection Projects (59 projects), shown in Figure 7.1.

From Table 7.2, it is seen that most of the projects are medium and small sized, as these types of projects give more benefits and have more impact than the large projects. It is also seen that a major number of projects were implemented during the period 1981-1990. The following decade (1991-2000), also saw a large number of implementation projects. Figure 7.2 presents a map showing the locations of major BWDB projects over the whole country.

(For details, and the list of BWDB projects, readers are referred to the BDP 2100 Baseline Study on Water Resources)

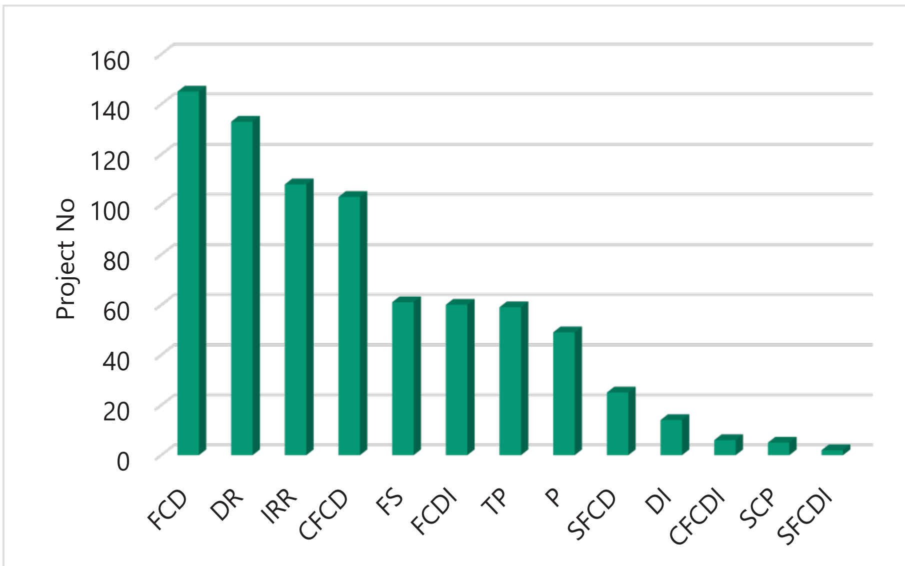


Figure 7.1: Categorization of BWDB projects

The production of food grains has been accelerated due to the successful implementation of the FCD/I project of BWDB, which can be tangible in Table 7.3, where the pre and post project rice production is demonstrated.

Table 7.3: Increase in rice production in some selected irrigation projects

Name of the projects	Pre-project production (Metric ton)	Post-project production (Metric ton)	Increased Production (Metric ton)
G.K. Project	203 493	628 588	425 095
Chandpur Irrigation Project	30 375	172 491	142 116
Pabna Irrigation Project	10 142	50 893	40 751
Meghna-Dhonagoda Irrigation	13 302	86 579	73 277
Muhuri Irrigation Project	27 000	138 375	111 375
Teesta Barrage Project	216 186	439 326	223 140
Total	*650 498*	*1 764 252*	*1 113 754*

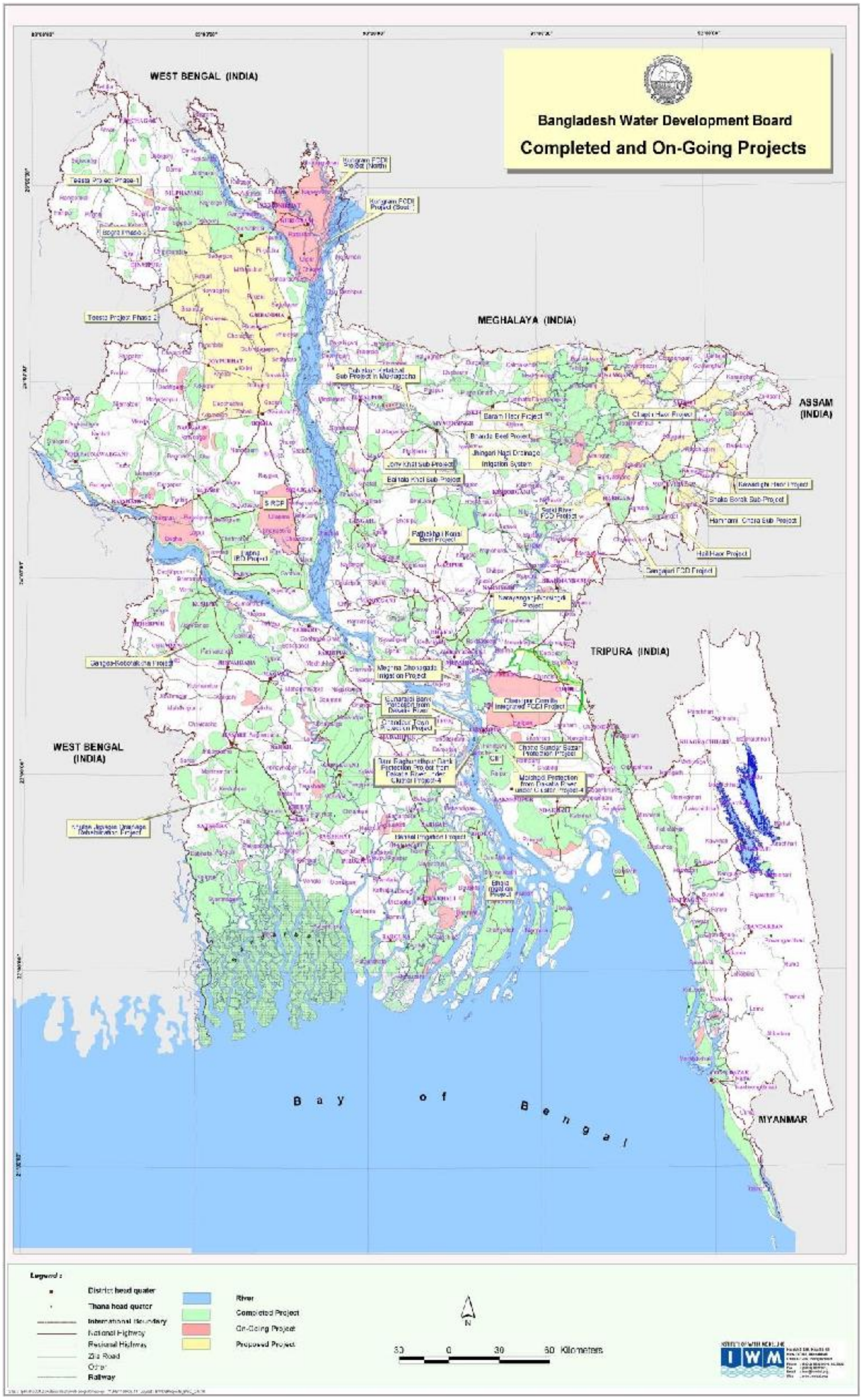


Figure 7.2: Map showing completed & on-going projects of BWDB

Source: IWM

To get a clear overview and concept, the completed projects are divided with respect to the following disciplines: flood management, irrigation management, coastal management, haor management, river management and feasibility study; out of which the flood management projects seem to be the highest in number. Approximately 302 projects have been implemented to manage the annual floods as well as flash floods around the country so far. On the other hand, haor region is the most deprived in terms of implementing such projects – only 27 projects comprising an area of 858,460 ha have been taken up till 2015. For irrigation management, coastal area management, river management and feasibility study, around 100-120 projects have been implemented under each category.

7.1 Flood Management

The purpose of the flood management projects is to convert F1, F2 or F3 land to a shallower flood phase, which facilitates conversion from Broadcast Aman to Transplanted Aman and from Local to High Yielding Varieties. As a result, the yields increase. Another benefit in the low lying areas is to protect the Boro Rice crop from the early flash floods, mostly in the North-Eastern region. For the coastal areas the main benefit lies in the exclusion of saline water. Three alternative options have been adopted for flood management. These are as follows:

- *Flood embankments with gravity drainage*: This type provides partial flood control, because during heavy downpour, the gravity drainage systems do not cope with volume of water being generated. Most of the large, medium and small projects fall under this category.
- *Flood embankments with tidal sluice drainage*: This type provides protection from tidal flood and associated salinity, mainly in the coastal region. All the coastal polders fall under this category. The drainage is only effective during low tides. Partial submergence within project area may occur during heavy rainfall.
- *Flood embankments with pump drainage*: This type provides full flood protection. Examples are: Chandpur Irrigation Project, Meghna-Dhonagoda Project, and Manu Irrigation Project etc.

7.1.1 *Policies and plans related to flood management*

Flood Management in Bangladesh has been under continuous progress since early 1960s'. Flood management strategies can be divided into three distinct phases of its development, which are as follows: Phase-I: 1960 to 1977, Phase-II: 1978 to 1996, and Phase III: 1997 onwards.

Phase-I: After two consecutive disastrous floods of 1954 and 1955, the implementation of large and medium FCD projects was given priority. During the implementation of these projects, some medium-scale floods occurred. As a result, it was realized that only structural measures, may not solve or mitigate the flood problems. In 1972, the Government decided to implement some non-structural measures, such as, flood forecasting and warning system to mitigate the flood problems (Ali, 2002).

Phase-II: While implementing some large FCDI projects, it was found out that large projects involve large investments as well, resulting in a long time to derive benefits. Government then opted for implementation of small and medium scale FCD projects to provide early benefits. After another twin disastrous floods in 1987 and 1988, the Government initiated Flood Action Plan (FAP), which was actively and financially supported by all international development partners. FAP was mainly a study project comprising 26 components, and carried out between 1990 and 1996.

Phase-III: To address the flood control issues in the light of Integrated Water Resources Management (IWRM) in the FAP studies, the Government intended to update the water planning to make a new master plan, thus resulting in formulating a National Water Management Plan (NWMP).

In the entire period 1954-2015, BWDB has implemented more than 300 projects for managing all types of floods in the country; normal and monsoon floods, and rain-fed and flash flood. Among the flood management projects, around 29% are small projects, 42% are medium projects, and 15% are large and very large projects.

Figure 7.3 illustrates the distribution of flood management projects (both structural and non-structural) in terms of project size by BWDB.

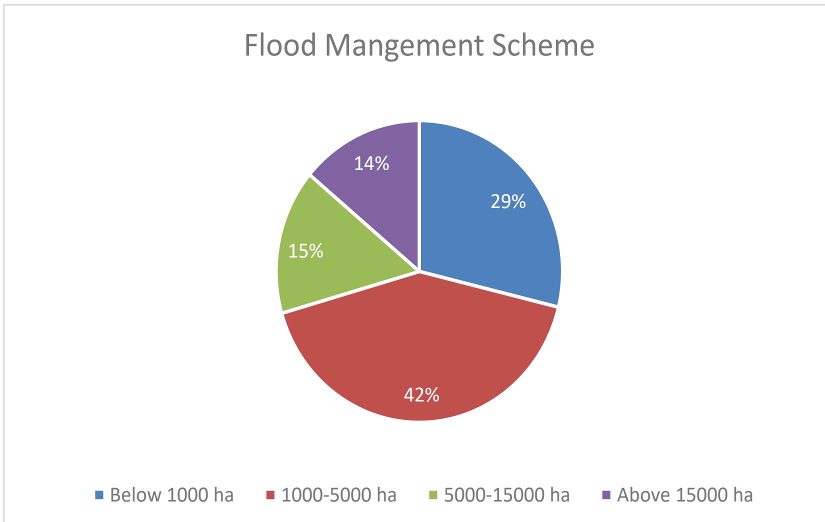


Figure 7.3: Distribution of BWDB projects for flood management in terms of project size

7.1.2 *Flood management by structural measures*

Structural option provided some benefits specially increase in agricultural production (BBS, 2013), at an early period of the project but some adverse effects were observed later on. Notably, the construction of high embankment along both banks of the rivers in some cases resulted in rise of bed levels due to siltation causing obstruction to drainage. In the coastal areas, although the construction of polders prevented salinity intrusion, it resulted in sedimentation of tidal rivers and obstruction to the gravity drainage; it also restricted the movement of the tidal prism. Structural measure caused many adverse effects on the aquatic lives, especially on open water fisheries. Wherever possible, FCDI projects were undertaken, with full and partial flood control facilities. Flood control and drainage structures were also provided in major cities to make the cities flood free such as Dhaka, Chittagong, Rajshahi, etc.

7.1.3 *Flood management by non-structural measures*

Introduction of non-structural option, i.e. Flood Forecasting and Warning System, Flood-cum-cyclone shelters, Flood proofing, etc started from early 1970s' and contributed to the improvement of the capacity for flood preparedness and mitigation/minimization of flood losses.

Flood Forecasting and Warning:

Flood warnings are intended to reduce sufferings to human life and damages to economy and environment. Flood Forecasting and Warning (FFW) Service of Bangladesh was established in 1972 as a permanent entity under BWDB. FFW activities run during the monsoon months, i.e. June to September, every year. In all the activities, field offices as well as the Flood Forecasting and Warning Center (FFWC) in Dhaka are closely involved. FFWC remains open on all days during this period.

Water level (WL) and Rainfall data are collected for daily operation of the real time FF model. Water level gauge readers are responsible for sending data of 85 WL stations every day. The rainfall data of every 24 hours are also collected from 56 stations. Most of the data are sent by SSB wireless sets as well as mobile phones. A pilot telemetry network covering 16 stations was established in 1996. This is mainly used to monitor the WLs of the major rivers at bordering stations. Hydrology Department of BWDB facilitates the data collection and transmission activities. The principal outputs of the Flood Forecast Model are the daily statistical bulletin of floods, river situation, descriptive flood bulletin, and forecast for 24, 48, 72, 96 and 120 hours at 54 monitoring points, special flood reports along with different graphical and statistical presentation during the monsoon season.

FFWC usually disseminate the flood information every day through different media of communication e.g. Internet, fax, telephone etc. and disseminate the flood information to different government departments, agencies, disaster managers, NGOs, news media etc. A recent study made by the Center to assess the response to its information by the people living in the flood-prone areas revealed that most vulnerable communities have no effective means of receiving timely information, despite the fact that the technology of flood forecasts in Bangladesh, as in many other countries, has reached a highly sophisticated level. This aspect of dissemination of flood information needs serious attention. Local Government Organization (LGOs) and Community Based Organizations (CBOs) can play an important role in this regard. Bangladesh has had successful experience in cyclone preparedness, and this can be used for flood preparedness as well. At the moment, pilot studies are being conducted to find out the best possible means for timely dissemination of flood information to the vulnerable communities.

Flood cum Cyclone Shelter:

School buildings are so constructed that they can be used as flood-cum-cyclone shelter especially in the coastal zone with high risk of flood and storm surge. These structures are not intended to change the flood regime, and therefore, considered as no-structural measures of flood management (GoB, 1995).

Flood proofing:

Efforts have been made to provide mitigation measures (rather than flood control) for the vulnerable communities by raising levels of homesteads, schools, and market places in low-lying areas and in the char lands so that farmers can save their livestock and food grain. Concept of flood zoning and flood insurance are not practiced in the country till date. Flood zoning will facilitate development in a co-ordinated way to avoid expensive investments in vulnerable areas. Proper land development rules should be formulated based on the flood-zoning maps.

Other non-structural measures practiced are:

- working with communities to improve disaster awareness
- develop disaster management plans
- relief and evacuation

7.2 Irrigation Management

Traditionally, the agriculture in the country is rain-fed, and the irrigation was limited to lifting water from wells, streams and water bodies to irrigate chillies, vegetables, boro rice, and betel leaf. In some cases, small pumps were employed for larger areas of boro rice and sugar cane. Irrigation project for large areas was unknown until the Ganges-Kobadak Project, Kushtia unit, was put under operation in early 1960s.

Groundwater irrigation was relatively new in the country. Though the groundwater was available, initially because of the high cost of development and operation of wells, groundwater irrigation was not an attractive option. But, in mid-1960, BWDB implemented Thakurgaon Tubewell Project, which was a concerted effort in groundwater development (at present Thakurgaon project is under BMDA). Subsequently, the responsibility of groundwater irrigation through deep tube well development, known as minor irrigation, was entrusted to BADC. At present, the groundwater irrigation development lies with the private sector.

Institutionally, major irrigation projects are the responsibility of the Ministry of Water Resources (i.e. BWDB). On the other hand, minor irrigation projects fall under the jurisdiction of the Ministry of Agriculture (i.e. BADC), and small-scale surface irrigation under the Ministry of Local Government, Rural Development and Cooperatives (i.e. LGED).

***Irrigation coverage*:** The irrigated area, served by both surface and groundwater, is about 6.32 million ha up to 2015. The expansion of irrigated land coverage from 1982 -2015 is shown below (Figure 7.4).

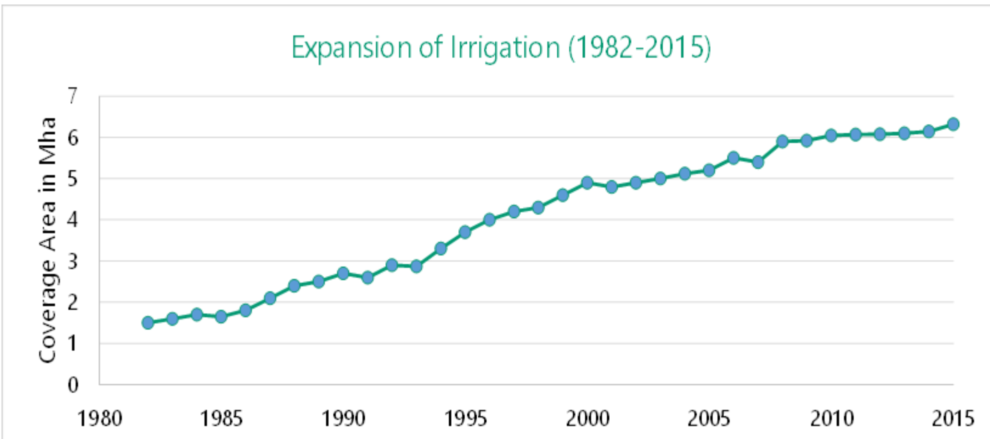


Figure 7.4: Expansion of Irrigation in Bangladesh (1982-2015)

***Surface water irrigation*:** The success of G.K Project Phase-I subsequently led to the development of many surface water irrigation projects such as Chandpur Irrigation Project, Muhuri Irrigation Project, Meghna-Dhonagoda Irrigation Project, Manu Barrage Project, Pabna Irrigation Project, Teesta Barrage Project etc to name a few. Besides these major projects, some other projects were undertaken. These projects covered some 1.6 million ha (BBS, 2013). Table 7.4 shows the major irrigation projects implemented by BWDB. Most of the irrigation projects are small scale, of which the implementing area is below 1000 ha (Figure 7.5).

The irrigation projects implemented by BWDB may be divided into four categories, in terms of coverage or impacted area, namely very large, large, medium and small projects. Most of the projects are small (64% of total irrigation projects), around 20% are medium and rest of the projects are 10% very large and 6% large.

Table 7.4: List of major (surface water) irrigation projects implemented by BWDB

Name	Location	Area
Ganges-Kobadak Irrigation Project (G-K Project)	Kushtia, Chuadanga, Jhenaidah and Magura districts (NW Region)	197,486 ha (Phase-I: 84,986 ha, Phase-II: 112,500 ha)
Chandpur Irrigation Project	Chandpur & Lakshmipur districts (SE Region)	54,036 ha (of which 24,291 ha is equipped for irrigation)

Name	Location	Area
Meghna-Dhonagoda Project	Chandpur district (SE Region)	19,021 ha (of which 14,400 ha is equipped for irrigation)
Muhuri Irrigation Project	Feni district (SE Region)	40,081 ha
Manu River Project	Moulvibazar district (NE Region)	22,580 ha (of which 12,090 ha is equipped for irrigation)
Pabna Irrigation Project	Pabna district (NW Region)	196,680 ha (of which 21,862 ha are equipped for irrigation)
Gumti Project	Comilla district (SE Region)	37,440 ha (of which 11,000 ha is equipped for irrigation)
Teesta Barrage Project	Rangpur, Lalmonirhat and Nilphamari districts (NW Region)	132,000 ha (of which 111,406 ha is equipped for irrigation)

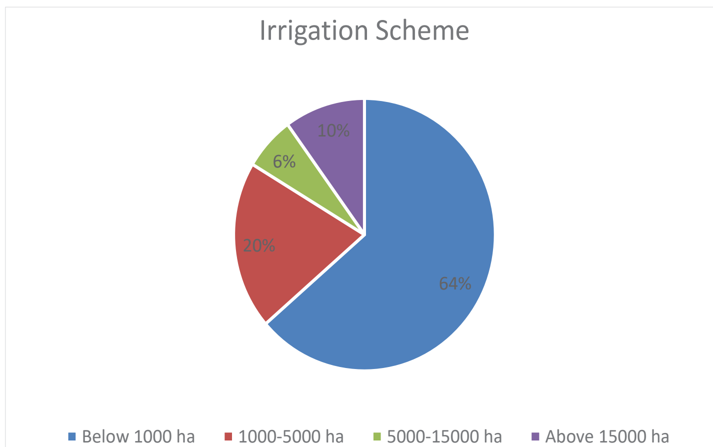


Figure 7.5: Distribution of Irrigation projects of BWDB according to project size

Minor Irrigation: The expansion of the minor irrigation has been outstanding in Bangladesh; minor irrigation covered 1.5 million ha in 1982, 2.6 million ha in 1990, and nearly 4.0 million ha in 1998. The 1997–98 National Minor Irrigation Census reported 3.82 million ha of minor irrigation, most of it private and locally managed (2.80 million ha). In 2006, total irrigated land was 5.4 million hectare (Mha) where 3.8 Mha i.e. 70% was under minor irrigation (BBS 2006). A recent study (Shamsudduha et al. 2011) shows that during the pre-developed groundwater-fed irrigation period (1975–1980), shallow tube well (STW)-based irrigation covered an average area of 57,000 ha and deep tube well (DTW) covered an average area of 138,000 ha. In a late study it is observed that, during the period 2002–2007, STW-based average irrigated area increased to 3,044,000 ha.

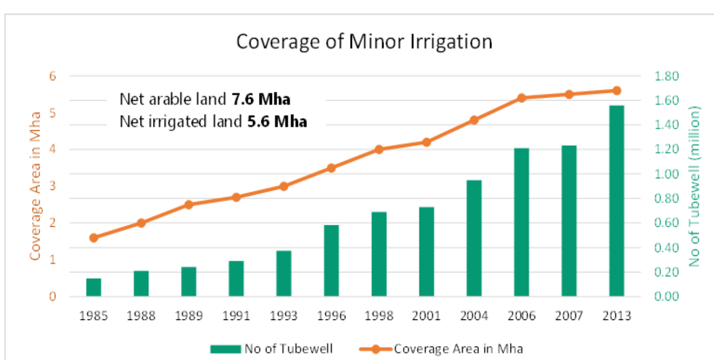


Figure 7.6: Development of minor irrigation (1985-2013)

From Figure 7.6 it is observed that, from 1985 till date the minor irrigation of Bangladesh is on increase. The number of tube wells in 1985 was around 0.2 million and in 2015 it reached to 1.6 million. The groundwater abstraction has increased massively. On the other hand, the area coverage of minor irrigation followed an increasing trend from 1985 to 2006, but it remained almost same from 2006 to 2013. The number of irrigation tube wells is on increase, but the area coverage remains the same. The possible reason for that might be due to increase in private tube wells in a particular region, where it was covered by a single tube well earlier. Another reason might be due to the implementation of irrigation projects, people are becoming more dependent on surface water for irrigation purpose, while for drinking purpose, they rely on tube well water.

BADC's achievement in irrigation: From 2009 to 2015, BADC has constructed small-scale for irrigation infrastructure in different places of the country as follows:

- Canal re-excavation: 7200 km
- Surface irrigation canal: 2006 km
- Underground irrigation canal: 1966 km
- Deep tube wells: 946
- Deep tube well rehabilitation: 1014
- Mechanical pump establishment: 3040
- Solar powered irrigation pumps establishment: 11
- Rubber dam construction: 8
- Irrigation infrastructure: 5732
- Embankments: 145 km

Rubber Dam Projects with Ministry of Agriculture: LGED introduced Rubber Dams in the country for the first time in 1995 to conserve water in the channels of small and medium rivers to enhance use of surface water for irrigation leading to increase in irrigated area and production. Since then, LGED has implemented 48 Rubber Dam subprojects. Among the LGED Rubber Dams, first 3 were pilot projects were with GOB funds, and the subsequent 29 were also funded by GOB under the Ministry of Agriculture and 16 were implemented under the Donor assisted LGED Projects. Rubber Dams have also been constructed by BADC (6) and BWDB (1) for similar purposes. Particulars of the Rubber Dam subprojects implemented by LGED are given in Table 7.5.

Table 7.5: Completed/Ongoing Rubber Dam Subprojects by LGED

Project	Funding Agency	Period	No of Dams	Location (District)	Cost (Lakh Tk)
1. Completed/ Ongoing Rubber Dam Subprojects					
Pilot Rubber Dams	GOB	1994-1998	3	Cox Bazar, Sherpur	770
10 Rubber Dams in Small & Medium Rivers	GOB	1999-2006	14	Dinajpur, Chittagong, Gazipur, Habiganj, Natore, Narayanganj, Sunamganj, Mymensingh, Moulavibazar, Panchagarh	4892
Small Scale WR Development Sector Project -2 (SSWRDSP-2)	ADB	2003-2008	9	Cox'sBazar, Chittagong, Mymensingh, Habiganj, Sunamganj	2731
Rubber Dams for Increasing of Food Production Project	GOB	2009-2016	15	Chittagong, Bandarban, Dinajpur, Moulvibazar, Khagrachhari, Lalmonirhat, Thakurgaon, Kurigram, Naogaon, Sherpur, Sunamganj	13985
Participatory Small Scale Water Resources Sector Project (PSSWRSP)	ADB	2010-14	6	Lalmonirhat, Chittagong, Cox's Bazar,	2000

Project	Funding Agency	Period	No of Dams	Location (District)	Cost (Lakh Tk)
Small Scale Water Resources Development Project (SSWRDP)	JICA	2013-14	1	Sherpur	1275
2. Planned Rubber Dam Subprojects					
Participatory Small Scale Water Resources Sector Project (PSSWRSP)	ADB	2014-18	6	Chittagong	2500
Small Scale Water Resources Development Project (SSWRDP)	JICA	-	2	Netrakona-Sunamganj, Habiganj	2500
Total			**56**		

7.3 Coastal Management

The coastal zone of Bangladesh spans over 710 km of coastline. The landward boundary of the Bangladesh coastal zone defined by three hydrological indicators: tidal influence, salinity intrusion and the influence of cyclones and storm surges. The exclusive economic zone (EEZ) is the seaward coastal zone. The coastal land zone extends over 32% of the country and includes 147 upazilas under 19 districts with 26% population of entire country (Table 7.6). It covers an area of 47,150 sq. km with a population of 38.5 million (BBS 2011,) resulting in an average population density of 817 persons per sq. km. The delineation of coastal zone is based on salinity, cyclonic storm surge and tidal amplitude. Because of the diversity of conditions across the coastal zone, it is useful to subdivide it into four areas, each of which has a distinct typical set of conditions and problems.

- South West (Ganges Tidal Floodplain – West)
- South Central (Ganges Tidal Floodplain – East)
- South East (Young Meghna Estuarine Floodplain)
- East and Hill (Chittagong Coastal Plains)

The coastal area is one of the most dynamic areas in Bangladesh. The vast inflow of sediments from the Ganges, Brahmaputra and Meghna are subject to coastal dynamic processes generated by tides, waves and currents that lead to accretion and erosion. Tidal amplitude ranges from approximately 1.5 m in the west to over 4 m in the east (up to 8 m at spring tide near Sandwip). In the western part one of the world's largest mangrove forests, the Sundarbans, is situated.

Main issues in the coastal management are the risks related to: (i) tidal floods, (ii) cyclones and storm surges (iii) river bank erosion and vulnerability of islands and chars, (iv) sea level rise, (v) salinity intrusion, (vi) water logging and (vii) coastal erosion. Much still remains to be understood of this dynamic delta. Table 7.6 shows an overview of the coastal districts and their exposure to the kind of risks.

Table 7.6: Overview of the Districts in Coastal Zone

SL	Districts	Area (km^2)	Population (2011)	Salinity	Tidal fluctuation	Cyclone risk
1	Barguna	1,832	8,92,781	√	√	√
2	Barisal	2,791	23,24,310	√	√	√
3	Bhola	3,403	17,76,795	√	√	√
4	Bagerhat	3,959	14,76,090	√	√	√
5	Chittagong	5,283	76,16,352	√	√	√
6	Chandpur	1,704	24,16,018		√	√
7	Cox's Bazar	2,492	22,89,990	√	√	√

SL	Districts	Area (km^2)	Population (2011)	Salinity	Tidal fluctuation	Cyclone risk
8	Feni	928	14,37,371	√	√	√
9	Gopalganj	1,490	11,72,415	√	√	
10	Jessore	2,567	27,64,547	√	√	
11	Jhalokati	758	6,82,669	√	√	√
12	Khulna	4,395	23,18,527	√	√	√
13	Lakshmipur	1,458	17,29,188	√	√	√
14	Narail	990	7,21,668	√	√	
15	Noakhali	3,601	31,08,083	√	√	√
16	Patuakhali	3,205	15,35,854	√	√	√
17	Pirojpur	1,308	11,13,257	√	√	√
18	Satkhira	3,858	19,85,959	√	√	√
19	Shariatpur	1,181	11,55,824		√	
CZ Total		47,203	38517698			
Bangladesh		147,570	14,97,72,364			
CZ (%)		32	26			

Development of Polders: The coast provides many natural resources, such as fertile lands, fresh and brackish water, forest and fish but living conditions are demanding due to freshwater limitations, salinity intrusion and frequent cyclonic storms, which can create huge surges of up to 6 m height. From the beginning, in the 1960's, construction of embankments started to protect land from tidal floods which ultimately led to the construction of polders (a polder is a low-lying tract of land enclosed by earthen embankments). In 2008, the polders supported a total population of 8 million people living on 1.2 million hectares of land (BBS, 2010) which gives a population density of 666 people per square kilometre.

***Coastal Embankment Project*:** The frequent flooding of the polders and intrusion of salinity coupled with increasing population, and need for more land and food, led eventually to the initiation of the Coastal Embankment Project (CEP) in late 1950s. Accordingly, the CEP was designed and implemented with the aim of preventing tidal flooding and salinity intrusion in the vast low-lying areas and thereby to increase the agricultural yields by rebuilding existing bunds and constructing new ones. This was perhaps the first large scale human intervention in the southwest coastal region of Bangladesh. About 139 coastal polders constructed during 1960s to early 1970s.

The immediate socio-economic consequences were very impressive and positive. The construction of a polder itself provided massive employment opportunities and stimulated local economies and trade. Transportation infrastructure dramatically improved, integrating new roads with navigation facilities, which enabled products marketed over long distances. Outputs of crops in all seasons were higher than in any time before and much more secure. At this time, better and more reliable control of water opened the door to other improvements in agricultural inputs and practices. Fishing remained significant, and the age-old tensions between fishermen and farmers persisted, but within acceptable tolerance.

This positive situation persisted for about two decades or so, but by the early 1980s, the secondary effects of polderisation in terms of sediment deposition began to be serious. The coastal rivers are tidal, and during low tides, due to slack current, sedimentation started to deposit on the riverbeds. Augmented by the restricted river flow upstream due to commissioning of Farakka Barrage, the situation gradually deteriorated. The restricted drainage and consequent waterlogging became a major issue in many parts of the coastal zone. Building of cross dams by influential people, removal of protective forests and vegetation, occurrence of few severe cyclones and enormous increase in population made the region even more complicated. The scenario changed the perception and led to new design approaches and some upgrading and rehabilitation efforts. The Coastal Embankment Project (CEP) is actually a rehabilitation of the affected polders in the coastal region.

***Land reclamation Project (LRP)*:** Prior to 1950s, the Meghna continuously eroded the Noakhali coasts and at one point, the district headquarters of Noakhali vanished. That led to the construction of the Cross Dam Number 1 and 2 in the later part of 1950s and earlier part of 1960s. In 1985, the building of the cross dam across the Muhuri in Sonaghazi, resulted in the formation of a big area of land (about 100,000 ha). However, due to the continuous process of accretion and erosion along the rivers and estuaries, the loss of valuable land occurred at one place and creation of new land at another. Every year thousands of families become landless. Riverbank erosion is the predominant reason for households to migrate to the unprotected islands or chars (Raza et al., 2011). Many people live on these chars and are subject to the fury of storms and coastal erosion. The consolidation of newly accreted land on these islands is hampered by quick colonization of people and cattle, preventing succession of vegetation that would otherwise stabilize the soil. In order to develop a long-term policy for land accretion works in the south-eastern coastal region of Bangladesh, BWDB initiated the Land Reclamation Project in 1980.

During the period 1954 – 2015, BWDB has implemented around 115 coastal zone-related projects, among these the major ones are described below. A number of initiatives have been taken in the past for the safety of the coastal zone in respect to life and property, agriculture, fisheries and livestock; which are stated in Table 7.7.

Table 7.7: Major projects implemented in coastal zone

Project Name	Year	Main objective
Coastal Embankment Project (CEP)	1970	Increase agriculture
Land Reclamation Project (LRP)	1980	Accretion of land
Cyclone Protection Project 1 (CPP 1)	1980	Cyclone shelter, early warning system
Cyclone Protection Project II (CPP II)	1990	Strengthening of coastal embankments
Coastal Embankment Rehabilitation Project	1991	Rehabilitate the damaged embankments
Second Coastal Embankment Rehabilitation Project (CERP II)	1997	Rehabilitation and improvement of water infrastructure
The Meghna Estuary Study (MES)	1998	Preparing of Master plan for estuary development
Char Development and Settlement Project (CDSP)	1994	Improve the economic and social situation of the Char population
Khulna Jessore Drainage Rehabilitation Project	2007	Removing drainage congestion
Gorai River Restoration Project (GRRP)	1996	Improve the flow of Gorai river during dry season
Integrated Coastal Zone Management (ICZM)	2009	Improve the management of natural resources
Coastal Zone Water Management Program		Feasibility study for rehabilitation
Coastal Embankment Rehabilitation Project	1995	O&M of coastal polders
Noakhali Drainage Project		Improve drainage for 320,019 ha area in Comilla, Noakhali, Laksmipur, Chandpur, and Feni districts
Estuary Development Program (EDP)	2009	Mitigation and management of coastal zone
Integrated Planning for Sustainable Water Management (IPSWM)		Sustainable water management by people's participation
Water Management Improvement Project (WMIP)	2012	Water resources management by rehabilitating damaged water related structures

Char Development and Settlement Project Phase IV (CDSP IV): The Char Development and Settlement Project, which was initiated in 1994, the Phase IV (CDSP IV, 2011- 2017)) was the fourth phase in a series of projects that have been developed in the newly accreted land (chars) in Bangladesh for over last two decades. The CDSP IV started in March 2011 and was co-financed by the Government of Bangladesh, the Government of the Netherlands, and the International Fund for Agricultural Development (IFAD). The project activities of CDSP IV focus on the development of five new chars: Char Nangulia, Noler Char, Caring Char, Urir Char and Char Ziauddin. These encompass around 30,000 ha area, with an estimated population of 155,000.

Coastal Embankment Improvement Project (CEIP): As an aftermath of cyclones SIDR and AILA, the Emergency Cyclone Recovery and Restoration Project (ECRRP) was taken up. A net area of about 100,817 ha of the project would be protected against events of 25 years return period for climate change conditions that would exist in 2050. Under this project the comprehensive Coastal Embankment Improvement Program (CEIP) was studied and implementation of the first phase of CEIP-1 was undertaken. Under this project 17 selected coastal polders would be upgraded and rehabilitated with the financial support from the World Bank (USD 400 millions). The objectives of the CEIP-1 were to: (a) increase the area protected in selected polders from tidal flooding and frequent storm surges, which were expected to worsen due to climate change; (b) improve agricultural production by reducing saline water intrusion in selected polders; and (c) improve the Government's capacity to respond promptly and effectively to an eligible crisis or emergency.

Blue Gold Program: The Blue Gold program will cover 25 polders with a combined area of 160,000 ha and will establish and empower rural community co-operatives to sustainably manage their defence, drainage and irrigation infrastructure (2013 –2017). Overall objective of the Program is to reduce poverty by creating a safe living environment and a sustainable socio-economic development for 150,000 household living on the 160,000 ha of polders. Additionally, advice will be given on irrigation, drainage, lands and fisheries management techniques to improve agricultural and aqua cultural productivity to generate more income.

Besides these typical coastal projects mentioned above, a number of river improvement plans have also been adopted, such as the Gorai River Restoration Project, the Ganges Barrage Project, Bhairab River Project and Kobadak River Basin Project. Other major projects relevant for coastal development are the Southwest Area Integrated Water Resource Planning and Management, Noakhali Drainage improvement, Sundarbans Biodiversity Conservation Plan, Cyclone Preparedness Programme (CPP) and Deep Sea Port Development Plans (Sonadia and Payra Port).

***Evaluation of past and existing plans and projects*:** The enormous amount of annual sediment discharged by the rivers provides a huge potential of land reclamation in the coast. Actually, this has been an on-going development over the past decades. The first cross dam constructed in the Lower Meghna in 1957 and many projects followed suit (e.g. Land Reclamation Project, Meghna Estuary Study, and Estuary Development Programme).

A major integrated land development project was the Char Development and Settlement Project (CDSP), which started in 1994 and is now in its fourth phase. The overall objective of CDSP–IV is to improve the economic situation and living condition of the population in the coastal areas of south-eastern Bangladesh with special reference to the poorest segment of the population. It started in March 2011 for the period of 6 years. The project has a number of innovative features, with opportunities of learning by the implementing agencies, the government and the donors. Unlike earlier char development projects, over half of the area will remain outside of the embankment (as it is too immature and unstable for impoldering). In order to generate benefits for the people living in these vulnerable chars, innovations such as salt-adapted agricultural technologies, house plinth raising and strengthening needs implementation. CDSP IV also plans to construct *killas* (raised mounds) as

refuges for livestock on such chars – something that earlier char development programmes did not do. Over the CDSP projects have evolved into a rather successful example of coastal development.

In order to tackle the problem of water logging, the concept of Tidal River Management (TRM) was introduced, which involves taking advantage of natural tidal movement in the river and adjacent low-lying flood plain. TRM allows natural movement of tide from the river to an embanked low-lying area (beel) through a link channel. During high tide, sediment-laden water enters into the low-lying areas where the sediments deposit owing to reduced velocity and long duration of storage. During ebb tide, the tidal water flows out of the low-lying area with reduced sediment load and erodes the riverbed and bank downstream. The natural movement of flood and ebb tide in the river and low-lying area increases the drainage capacity/conveyance of the river through scouring and maintains the river navigability. Subsequently the low-lying area is raised considerably due to deposition of silt. The TRM process is an example of building with nature and a resilient measure for water-logging, river sedimentation and subsidence. TRM has been applied in several beels (water bodies) under the Khulna-Jessore Drainage Rehabilitation Project (KJDRP).

Institutionalization of integrated coastal management has been attempted in recent years through a number of initiatives; the Coastal Embankment Improvement Project (CEIP) and the Char Development & Settlement Project (CDSP) may be mentioned in this respect. These projects provide a good example of inter-agency interaction and cooperation. This may be considered as a key achievement in Coastal Management in Bangladesh (E Humphreys, 2015).

7.4 Haor Management

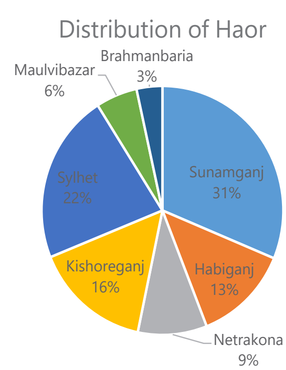
The Haors – the inter-riverine areas or wetlands between river channels – consist of dish-shaped depressions within a perimeter consisting of natural river levees. The haor lands include the lower external slopes of levees, which merge at a central location to form an extensive inter-riverine depression. The haor lands lie, in general, at elevations between sea level and +5m PWD, and are flooded from the surrounding rivers every year during the monsoon whether they are still in their natural state or have been enclosed by submersible embankments. During monsoon, the haors are flooded and overtop the levees and back up the khals until the haors are completely under water. As seen from the air in this season the central part is one large lake; the perimeter of which runs roughly through Bhairab Bazar, Kishoreganj, Sunamganj, Chhatak, Sherpur, Habiganj, and back to Bhairab Bazar. Large areas are also flooded to the east of the central basin between Chhatak, Sylhet, Amalshid and Moulvibazar.

The haor areas in the north-eastern region covers about 1.99 million ha (19,998 sq km) of area and accommodates about 19.37 million people. There are 373 haors/wetlands located in the districts of Sunamganj, Habiganj, Netrakona, Kishoreganj, Sylhet, Moulvibazar and Brahmanbaria. These 373 haors cover an area of 858,000 ha. Number of haors and the areas in haor districts are given in table below:

Table 7.8: District wise number and area of haor

District	Total area (ha)	Haor area (ha)	No of haor
Sunamganj	367,000	268,531	95
Habiganj	263,700	109,514	14
Netrakona	274,400	79,345	52
Kishoreganj	273,100	133,943	97
Sylhet	349,000	189,909	105
Moulvibazar	279,900	47,602	3
Brahmanbaria	192,700	29,616	7
Total	1,999,800	858,460	373

Source: Haor Master Plan, 2012



The haors mainly comprises prime agricultural land, but their seasonal inundation severely constrains agriculture. In most Haors a boro rice crop only can be grown (dry season), and this is liable to damage by flash flooding usually in the pre-monsoon season, but also earlier. The haors also comprise an important part of the regional fisheries environment. When the areas are flooded at the beginning of the monsoon, fish migrate into the haors to feed and/or to spawn, and as the haors drain in the post-monsoon period the fish migrate back into the main river system.

Two types of embankments have been constructed around half the haors. The most common type is the submersible embankment, intended to provide flood protection to the boro crop up to 15 May by when it is normally harvested. A few full-height embankments have also been constructed to provide year-round protection to all crops. Submersible embankments normally contain one or several regulators, which are closed while the boro crop is on the land and then opened after 15 May to flood the haors before the embankment is over-topped by monsoon flooding. The purpose of flooding the haors via the regulators is to limit erosion of the embankments during over-topping by ensuring that the water level difference across the embankment does not exceed 30 cm when over-topping begins.

While the haor embankments usually protect boro rice crops from flooding in the dry and pre-monsoon (harvest) seasons, the structures can cause problems. Farmers, fishermen and boatmen sometimes respond by cutting the embankments to enable land drainage in the post-monsoon period, to allow fish catches at the cuts (usually in the pre-monsoon period), and to provide shorter routes for country boats during the monsoon. If the cuts are not repaired during the dry season the boro crops are at risk of damage in the pre-monsoon season.

Before the formation of the Haor Development Board, BWDB worked in the haor areas and made 290 thousand hectares of land cultivable for boro paddy. It constructed *1826 km long submersible embankments* to protect these crops from flash flood. These interventions in the haor area were affected by BWDB through different projects, namely Early Implementation Project (EIP), System Rehabilitation Project (SRP), Flood Action Plan (FAP), Haor Rehabilitation Projects, etc. Until now, 123 projects were implemented by BWDB in about 754,949 ha of haor areas as shown in Table 7.9.

Key achievements in haor management are as follows:

- An integrated Master Plan incorporating sustainable and appropriate strategy and management has been formulated for comprehensive development of haor areas;
- *Bangladesh Haor and Wetland Development Board* (now Department) has been created in 2000 for integrated development of haor areas under the Ministry of Water Resources.

Table 7.9: Haor management projects implemented by BWDB

Type	Number of Projects	Area Coverage (ha)
Drainage	1	3,058
Flood Control and Drainage	65	393,473
Flood Control	10	33,565
Flood Control Drainage and Irrigation	46	324,165
Irrigation	1	688
Total	123	754,949

7.5 Small Scale Water Resources (SSWR) development by LGED

Works on SSWR development dates back to 1960s when small projects, mostly on surface water-based irrigation, were implemented by the Thana Irrigation Program (TIP) under the Works Program of the Government. During 1986-1996, LGED implemented 60 SSWR projects under the Rural Employment Sector Program assisted by the Swedish International Development Agency (SIDA). Based on experience of these earlier water resources development activities, LGED was entrusted to implement the first program on small scale water resources development, the SSWRDSP (1995-2003) assisted by the ADB in 37 western districts of the country ensuring participation of the beneficiaries and other local stakeholders in the process of subproject implementation and subsequent O&M by establishing beneficiaries' Participatory Water Management Cooperative Association (WMCA). In the meantime, the NWP was formulated which defined the role of Local Government Institutions (LGI) in water resources development and given the mandate of implementing flood control, drainage and irrigation (FCDI) subprojects having benefited areas of up to 1000 ha. The NWP emphasizes that water resources management requires involvement of public and private sectors, communities and individuals that benefit from the delivery of water-related sectors. Following the successful completion of SSWRDSP-1 and promulgation of the NWP, LGED implemented the ADB-assisted SSWRDSP-2 (2002-10) and is now implementing the JICA assisted SSWRDP (2007-15) and the third ADB assisted PSSWRSP (2010-11 to 2017-18). Details of the projects are given below (Table 7.10).

Table 7.10: Small Scale Water Resources Development Projects by LGED

Name of Project	Assisting Agency	Implement Agency	Implement Period	Project Area	Target Area (ha)	Cost Crore Tk	Status
Small Scale Water Resources Development Sector Project (SSWRDSP)	ADB	LGED	1995-96 to 2002-03	37 Districts of Rajshahi, Khulna, Barisal & Greater Faridpur District	162,000	264.86	Completed
Second Small Scale Water Resources Dev Sector Project (SSWRDSP-2)	ADB	LGED	2002-03 to 2009-10	All over Bangladesh (excl. 3 hill districts)	180,557	438.82	Completed
Small Scale Water Resources Development Project (SSWRDP-JICA)	JICA	LGED	2007-08 to 2014-15	16 Districts of Gr. Mymensingh, Sylhet & Faridpur Areas	130,000	557.5	On going (70%)
Participatory Small Scale Water Resources Sector Project (PSSWRSP)	ADB	LGED	2010-11 to 2017-18	46 Districts exclude. 3 hill districts and 15 districts under JICA assistance	220,000	471.65	On going
Capacity Dev Project for Participatory Water Resources Management through Integrated Rural Development	JICA (TA)	LGED	2012-17	IWRM Unit, LGED	-	-	On going

7.6 River Management

The country has a vast network of rivers totalling to 405 according to the latest statistics of BWDB. These include three major rivers and multiple medium and small rivers. The rivers are characteristically dynamic with frequent shifting of banks. So far, the river management has not been done comprehensively; instead, sporadic interventions have been made over the decades to protect the towns, growth centres, and embankment from river erosion. These are site-specific interventions in the form of hard points, revetments, groynes, spurs, dredging etc.

The three major rivers (Brahmaputra/Jamuna, Ganges/Padma, and Meghna) influence the hydrological as well as morphological characteristics of the other rivers significantly. Thus, any changes in these rivers become the drivers, which may influence the overall socio-economic condition of the country. According to CEGIS, from 1973 to 2014 around 90,000 ha of land have been eroded along the Jamuna River, but only 16,000 ha of land have been accreted. Along the Padma River the erosion and accretion are approximately 33,000 ha and 12,000 ha respectively. However, in the Ganges and the Lower Meghna, the rate of erosion and accretion are almost equivalent. Figure 7.7 represents the status of erosion and accretion along the major rivers between 1973 and 2014.

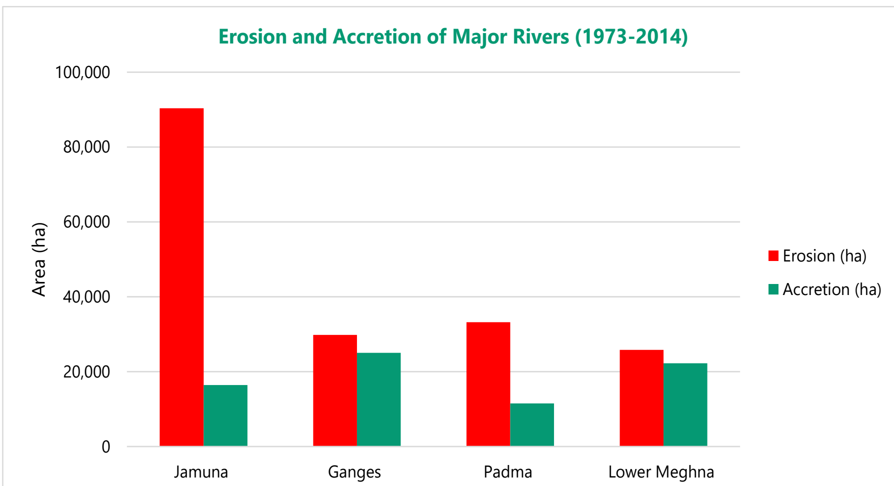


Figure 7.7: Erosion and accretion along the major rivers

Over the years, BWDB constructed about 70 large hydraulic structures on the three major rivers; the number of river management works so far carried out by BWDB is shown in the following pie chart (Figure 7.8).

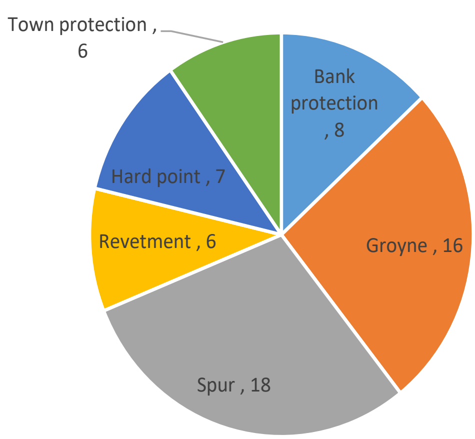


Figure 7.8: Category of completed protective measures on the three major rivers

7.6.1 *Protective measures on the Jamuna River*

The Brahmaputra-Jamuna is one of the largest braided rivers, which is still in the process of development. Erosion has been the dominating morphological process in this river during the last few decades. Since 1973, a large area of floodplain (90,830 ha) has been eroded by the river, with only a small amount of land (10,140 ha) gained during this period. Annual river bank erosion was very high in the 1980s (about 5,000 ha/yr) and as a result, the rate of widening of the river was also very high. During the first decade of this century, the annual rate of riverbank erosion dropped to 2,000 ha/yr. BWDB constructed many interventions along the Jamuna River and carried out a lot of river training works as well as constructed hard points to address the problem (Figure 7.9).

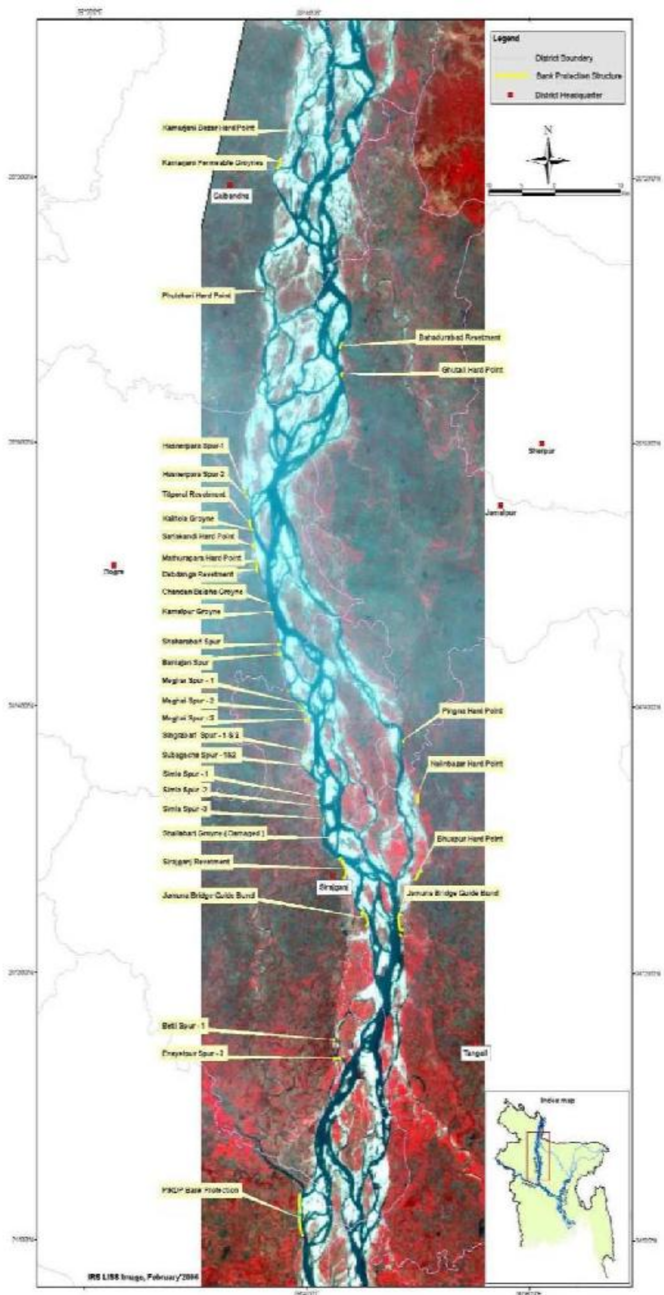


Figure 7.9: Locations of different river bank protection structures on the both banks of Jamuna River

Five hard points at Sariakandi, Mathura Para, Pigna, Nalin Bazar and Bhuapur have been constructed and a number of revetments, groynes, spurs have also been constructed over the decades. The revetment at Kamarjani, Bahadurabad, Titporal, Debdanga, Ranigram; Ghutail, Groyne at Kalitola and Kamalpur; spurs at Enayatpur and Betil etc are the landmark achievement of BWDB. The list of development projects so far carried out on the Jamuna River is shown in Table 7.11.

Table 7.11: Project interventions on Jamuna River

Component	Bank	Intervention	Length (km)
Kamarjani Revetment	RB	Revetment	158.10
Kamarjani Permeable Groyne	RB	Groyne	2607.54
Fulchari Ghat	RB		225.41
Bahadurabad Revetment	LB	Revetment	975.67
Ghutail Bank Protection	LB	Town Protection	658.76
Hasenpara Spur 1	RB	Spur	389.37
Hasenpara Spur 2	RB	Spur	344.72
Titporal Revetment	RB	Revetment	1822.75
Kalitola Groyne	RB	Groyne	226.00
Sariakandi Hard Point	RB	Hard Point	635.84
Mathura Para Hard Point	RB	Hard Point	535.63
Debdanga Revetment	RB	Revetment	1357.36
Kutudpur bank protection work	RB	Bank Protection	1301.72
Chandan Baisha Groyne	RB	Groyne	181.28
Kamalpur Groyne	RB	Groyne	309.65
Saharapara Spur	RB	Spur	658.65
Baniajan Spur	RB	Spur	816.87
Meghai Spur 1	RB	Spur	1473.80
Pigna Hard Point	LB	Hard Point	603.58
Nalin bazar Hard Point	LB	Hard Point	1341.06
Simla Spur 2	RB	Spur	284.86
Ranigram Revetment	RB	Revetment	4127.40
Bhuapur Hard Point	LB	Hard Point	1556.49
Jamuna Bridge Guide Bundh	RB	Bridge	3221.13
Jamuna Bridge Guide Bundh	LB	Bridge	3205.51
Betil Spur 1	RB	Spur	740.94
Enayetpur Spur 2	RB	Spur	1213.69
JMREMP Geo-bag Protection	RB	Bank Protection	10052.80
PIRDP Bank Protection	RB	Bank Protection	5743.61

7.6.2 *Protective measures on the Ganges River*

The Ganges is also a large meandering river with alternating expansions and contractions. After the commencement of the Farakka Barrage, the drastic reduction of annual dry season flow and discharge in the mid-1970s has been observed mainly due to the flow diversion. In the 1980s and 1990s, the annual rate of riverbank erosion was around 1000 ha/yr as the large meandering bends was in the development phase at that time.

Like the Jamuna River, BWDB has constructed many river training works as well as hard points on the Ganges River also; the notable ones being the two hard points at Bheramara and Pakshi. Godagari Revetment, Charghat Revetment, Pakshi-Bheramara Guide Bund, Pakshi-Ishwardi Guide Bund, Spur-3 Guide bund are the other important interventions done by BWDB on the Ganges.

7.6.3 *Protective measures on the Padma River*

The Padma is the combined flow of the Jamuna and the Ganges, stretching from Aricha to its confluence with the Meghna near Chandpur. During the last few decades, the Padma has changed its planform from braided to straight channel causing erosion and accretion. At present, average width of the river is about 10.5 km. The annual maximum erosion rate sometimes exceed 1,000 m/yr in case of highly erodible bank materials, whereas the maximum erosion rate may be limited within a few meters per year in the case of less erodible bank materials. The river bank has been guided by a number of protection measures and a large length of protection works which were mainly implemented by BWDB. Among them, the town protection and the construction of embankment are the major activities. It is observed that most of the projects along the Padma are operated on the right bank of the river, especially to protect Faridpur district head quarter. The list includes Hasail-Banari protection, Faridpur Town protection, Chandpur Town protection, etc.

7.6.4 *Protective measures on the Meghna River*

The district head-quarters of Narsingdi, Chandpur, Barisal and Bhola stand on the banks of the Meghna. Kuliarchar, Bhairab Bazar, Chandpur (Puran Bazar, Natun Bazar), Ramdaspur, Kalupur and Daulatkhan are important river ports and business centres, i.e. Ashuganj thermal power plant is located on the left bank of this river. The bank erosion and frequent char development are the main problems and the rate of erosion is around 800 ha/yr, because of char formation. The other notable bank protection projects are the Bank Protection of Meghna-Tentulia (Phase-I), Protection of Chandpur Irrigation Project at Haimchar and Ibrahimpur, the protection of Daulatkhan town, the Protection Polder 73/1.

7.6.5 *River improvement dredging*

BWDB has implemented some projects for restoring the river flows and navigability by river training and dredging. Two such dredging projects were Gorai River Restoration Project and Pilot Capital Dredging of the Jamuna. After the commissioning of the Farakka Barrage, the flow in the Gorai River considerably decreased. In order to restore the flow, some restoration programs were undertaken. But the result was not encouraging. Following the Ganges Water Sharing Treaty in 1996, the off-take was restored and maintained for several years under the *Gorai River Restoration Pilot Project*. After 2005, the off-take was again silted up and a second phase of the project was taken up during 2009 to 2014 to restore the flow. The objective of the project was to prevent environment degradation in the south-western region especially in Khulna, the coastal belt and the Sundarban through ensuring fresh water flow in the dry season, good quality of drinking water for household, reducing salinity below 1 ppt in groundwater at Khulna, and reducing salinity below 20 ppt in the Sundarban Zone for the protection of biodiversity.

***Pilot Capital Dredging of the Jamuna*:** The Capital (pilot) Dredging of the Jamuna was implemented in 2010 at two locations at Sirajganj and Nalin Bazar. The Jamuna River from upstream of Sirajganj Hard Point through Bangabandhu Bridge to Dhaleswari off-take (20 km) were dredged to divert the flow from the west channel into the mid channel to reduce the risk of failure of Sirajganj Hard Point and to guide the flow along the middle of the existing char through the Bangabandhu Bridge to Dhaleswari off-take. Likewise, the channel of Jamuna in front of Nalin Bazar near Bhuapur-Tarakandi Road (2 km) were dredged to divert the flow from the existing left anabranch of the river for reducing erosion in order to protect the existing Bhuapur-Tarakandi road-cum-embankment. In order to achieve the objectives of pilot dredging, four cross-bars along the right bank of the Jamuna and one cross-bar near Nalin Bazar were also constructed using the dredged spoils (16 km^2 land was reclaimed using dredged spoils).

7.6.6 *River Conservation*

The River Conservation Commission started operation in collaboration with the Ministries, Divisions, Departments and Agencies that are concerned with pollution prevention, conservation and management of rivers. The commission will mainly make recommendations and coordinate the role of various government agencies involved with rivers, they will draw up an action plan to restore four rivers around Dhaka on priority in keeping with the court order and then take care of other rivers. It will also coordinate the activities of different ministries and departments and provide suggestions for protecting the rivers as well ensuring multi-dimensional uses of rivers for socio-economic development of the country. There are over a dozen government agencies involved in different aspects of river management.

7.7 Urban Protection

Many cities, towns and growth centres are located on the river banks. These places occasionally face river erosion. In order to protect these places, the bank protective measures were taken from time to time. An analysis shows that 33 urban areas including the major cities of the country were provided river bank protection facilities.

Dhaka Integrated Flood Protection Project: After the disastrous flood of 1988, this project was taken up to take care of flood protection and drainage works. Three executing agencies worked together; BWDB was responsible for flood protection works, DWASA for drainage improvement, and DCC for environmental improvement. The project covers an area of 136 sq km and includes about 87% of the total urban population and some 95% of the commercial and industrial properties in the city including the Dhaka International Airport. The Airport Road roughly demarcates the eastern and western part of the Dhaka city. An embankment was constructed on the left bank of the Turag, the Tongi Khal and the Buriganga and three major pumping stations were constructed, two on the western side (Goran Chatbari operated by BWDB and Mohammadpur operated by DWASA) and one on the Dholai Khal (operated by DCC). Another small pumping station was constructed on the Begunbari Khal at Rampura.

During 1998 and 2004 floods, it was observed that the pumping stations could not be operated in full capacity, because of the encroachment of the ponding areas. The capacity of the pumping station at Rampura was not adequate to drain out the volume of water generated in the protected area. Since then the capacities of the pumping station have been increased.

Protection of the Port City Chittagong: During the 1991 cyclone, the port city was found to be highly vulnerable to the cyclonic storms. This led to the strengthening and heightening of the embankment of the Polder 62 on the left bank of the Sandwip Channel and placing of very large blocks (1.0 m x 1.0 m) on the slopes of the embankment in the vicinity of outfall of the Karnaphuli River.

Secondary Town Protection: The protection of secondary towns from flooding was one of the many FAP studies undertaken in the early 1990s. The FAP 9A and 9B studies identified flood problems in 16 secondary towns. In the first phase of the Secondary Towns Integrated Flood Protection Project (Phase-I), six towns, namely, Khulna, Dinajpur, Panchagarh, Kurigram, Habiganj and Moulvibazar were included and the flood protection works were completed during 1994 to 2000. The phase two of the Secondary Towns Integrated Flood Protection Project (STIFPP-II), commenced in September 2003. The project had two executing agencies – BWDB and LGED. Under this arrangement BWDB was responsible for the flood control and river bank protection works, and LGED the structural part. The broad objective of the project was to create a flood free and secured environment in nine towns, namely, Kushtia, Rajshahi, Gaibandha, Jamalpur, Mymensingh, Manikganj, Munshiganj, Brahmanbaria and

Sunamganj. The development objectives of the project were flood protection works, rehabilitation of drainage facilities, sanitation improvement, solid waste management and slum improvements. To promote sustainable and long-term development, these projects also supported institutional and policy development – including cost recovery, financial management, urban management, and operation and maintenance.

Besides these, the river erosion protection facilities were provided to about 179 upazila and growth centres under River Protection & Development and Town Protection Project- Phase III and IV.

7.8 Participatory Water Management

During 1960s, the operation and maintenance of the irrigation structures was done by the project authority engaging staffs in the G. K. Project Phase I. The field channels were excavated departmentally. In order to involve the farmers in water management, the *chashi* (farmers) clubs were established and gradually they were trained in water management. Much effort has been expended in the past two decades to review stakeholder participation under the Dutch-aided Early Implementation FCD projects, and IDA/CIDA assisted small-scale FCDI projects. This initiative was later enforced through Flood Action Plan (FAP) studies and the System Rehabilitation Project (SRP) of BWDB. In 1994, the 'Guidelines of Peoples Participation' was formulated. These guidelines focused mainly on irrigation projects and not on flood-control projects. BADC and LGED followed other approaches to people's participation, which, in turn, created conflicts at field level. Later, realizing the necessity of the community participation in flood-control and drainage projects, a new Guidelines for Participatory Water Management (GPWM) was formulated in 2000 taking past experiences into consideration. GPWM was made applicable to all flood-control, drainage and irrigation projects.

GPWM's institutional framework, in which local stakeholders would participate, is made up of a three-tiered Water Management Organization (WMO): a Water Management Group (WMG), a Water Management Association (WMA) and a Water Management Federation (WMF). According to the National Water Policy (1999), the management of the medium projects (from 1 001 to 5 000 ha) will be transferred to WMOs and the management of the projects greater than 5 000 ha will be under the joint management of BWDB, LGIs and Joint Management Committees. These WMOs will be responsible for planning, implementing, operating as well as maintaining the FCD/I projects in a sustainable way. BWDB formed a total number of 5 WMFs, 142 WMAs and 2185 WMGs in 122 projects up to June 2015 and are registering these to provide legal coverage. The members of WMOs are being trained to enhance their capacity for operation and maintenance of infrastructure as well as water management of the projects and collecting service charges.

A number of important water sector projects where the community participated are described below.

Coastal Embankment Rehabilitation Project (CERP): In 1996, the government, with financial assistance from the World Bank and the European Union, launched the CERP to undertake massive rehabilitation works for twenty-one coastal polders. It was observed that a large number of squatters occupied the embankments during the floods and cyclones. These settlements caused harm to the embankment system. A study recommended the inclusion of the squatters in the embankment maintenance system as an integrated project component. Accordingly, the squatters were allotted some reach of embankment on the condition of maintaining the surface on a regular basis including planting vegetation cover, for which they would receive financial assistance. They also received training through some NGOs. A community-based O&M plan was prepared in consultation with the community. Where there was no squatter, Embankment Maintenance Groups (EMGs) were formed. All routine maintenance was done at the community level, except for larger damages beyond community capabilities, which were undertaken by BWDB. This would result in saving a lot of govt's O&M expenditure.

Khulna-Jessore Drainage Rehabilitation Project (KJDRP): This project, located in southwest region, has a total project area of 127,800 ha and includes 1.1 million people. Like other polders, siltation in polder nos. 24, 25, 27 and 28 occurred in early 1980s'; these polders formed the area under KJDRP. Due to river deterioration, the rainfall runoff created drainage congestion in the polder areas, causing the inundation of farmlands and households, and disrupting the internal communication networks, leading to acute environmental degradation, loss of agricultural production, decreased employment opportunities and lowered living standards of the people of the area. A community-focused participatory approach was adopted in June 1995. The community was associated with project management in the rehabilitation of a relatively new technology known as Tidal River Management (TRM). The community also participated in finalizing the design of the drainage structures and canal networks for ensuring effective drainage. WMOs actively participated in the construction of perimeter embankments in some places by procuring land free of cost from the beneficiaries and helping the contractor to mobilize the labour force. WMOs helped to collect basic data and information through field surveys and disseminated information among the beneficiaries. This was a unique example of community participation in the design, planning and implementation of a large drainage project and in finding a viable solution. The drainage congestion of the affected areas has been considerably reduced.

Command Area Development Project (CADP): This project sought to bring about sustainable increase in dry season agricultural production, by realizing the full potential of the irrigated areas: 13,632 ha in the Meghna-Dhonagoda Irrigation Project (MDIP) and 18,870 ha in the Pabna Irrigation & Rural Development Project (PIRDP) thorough participatory management. CADP provided water management training and O&M facilities to the community, as well as project staff for the development of command areas, integrated pest management training and the development of small-scale fisheries. The WMOs participated in the decision-making process of the rehabilitation works, the O&M of the project facilities and the collection of irrigation service charges from the farmers. Small construction works were done by the LCSs. Through this programme, the landless workers themselves profited from the contracts. In major civil work contracts, the community was involved in construction supervision as members of Quality Monitoring Committees. The community was also involved in the operation of pumps, gates and in rotational irrigation.

Water Management Improvement Project (WMIP): The project was taken up aimed at enhancing the capacity of the local community to improve the performance of the water management systems. The overall objective was to alleviate rural poverty by creating better livelihood opportunities for the local population. This project sought to achieve this objective by initiating the participatory water management approach. The outcome of project was the improved water resources management capacity, reduced vulnerability, enhanced livelihood opportunities as well as improved institutional performance and good governance. The project supported, through pilot testing, the establishment and strengthening of WMOs and subsequent mainstreaming of participatory planning and project assessment.

An evaluation of the project was conducted by SMEC, DDC & ACE consultant team on 2015 (SMEC, 2015). The report stated that, the Water Management Group (WMG) and Water Management Association (WMA) were not existent in 72% of sample schemes. In the remaining 28% schemes, WMGs were existed; however, they were mostly non-functional. This situation has significantly changed as a result of WMIP implementation. By the end of April 2015, around 785 WMGs and 72 WMAs had been organized. The number of organized Water Management Organizations (WMOs) in the 32 sample projects of BWDB had increased to 414 breaking the target by 50%.

South-West Area Integrated Water Resources Planning and Management Project (SWAIWRPMP): This project is the ultimate outcome of a preparatory Technical Assistance (PPTA) of ADB following five regional studies of FAP. The project period was from October 2005 to 2015, and covered 100,000 ha of flood control drainage/irrigation areas, including the districts of Faridpur, Gopalganj, Jessore, Magura, Narail, Rajbari and

Shariatpur. Overall, the project's main objectives included (i) participation of beneficiaries in the planning of project works; (ii) improved management of water resources; (iii) renovation of existing flood control, drainage, and irrigation systems; (iv) development of the capacity of water management organizations; and (v) delivery of services that supported income-earning opportunities in the agriculture and fisheries sectors.

The major activities in the projects were building or re-sectioning of embankments (30 km), excavation of khals (246 km), constructing/repairing regulators, hydraulic structure (74 no), installing deep tube wells (122 no) etc. Under this project, 102 WMG, 14 WMA and 2 JMC were formed with 32 new office buildings. These associations and groups include a total of 25,424 members, including 10,119 women. More than 80% of the farmers in the subproject areas are members of WMGs, 40% of these members are women. The tangible benefits envisaged by 2015 of the Project are: increased cropping intensity by 30%; increased annual cereal production by 166,000 tonnes, other crops by 72,000 tonnes and culture fish by 5,000 tonnes; increased gross margin per farm family by 40%; permanents employment by 7.2 million man-days; and annual family income of landless labourers by Tk. 2000.

The Integrated Planning for Sustainable Water Management (IPSWAM): IPSWAM Programme has been planned based on the lessons learnt in the Bangladesh water sector. Total project duration was the five year period started from November 2003 to November 2008 plus an extension period up to 30 June 2011 for repairing damages to the infrastructure caused by the SIDR and AILA cyclones in nine polders. Major planned and executed rehabilitation works included repair of 54 drainage and flushing sluices, irrigation inlets, re-sectioning of 307 km embankments, re-excavation of 242 km khal, construction of 202 irrigation inlets & 20 drainage outlets, etc. Total households of local stakeholders were about 66,033. However, 68,761 numbers of local stakeholders have been enrolled in WMG up to November 2011 of which 40,206 was of male and 28,555 of female.

Observation on the PWM: The concept of Water User Groups becoming responsible for water management O&M and organized into a multi-tier organization was well adopted. A three-tier Water Management Organization (WMO) is foreseen consisting of WMG, WMA and WMF. The principles that govern the establishment of these organizations are laid down in the NWPo. The concept of Water Management Co-operative Associations (WMCA) has been in place since 1987 when LGED pioneered this form of organization. The lead has been taken by projects such as IPSWAM and CDSP. A key issue remains the lack of sustainable financing of O&M, at project and catchment level.

Hussain (2004) reported from the practice of GK and KJDRP that there was lack of access to systematic technical information of farmers resulting in poor participation in operation and maintenance phase of the projects. Moreover, Andreasson (2012) stated through reviewing the BWDB implemented Fourth Fisheries Project, the conflict between shrimp and paddy systems arose while deciding on the operation of sluice gates; this further exacerbated the conflict and this element of the project had to be thwarted. Another reason, the practice of Participatory Water Management was hampered by the inadequate funding and misallocation of the approved funding.

WMIP was a success story of BWDB. An evaluation of the project was conducted by SMEC, DDC & ACE consultant team on 2015 (SMEC, 2015). The report stated that, the Water Management Group (WMG) and Water Management Association (WMA) were not existent in 72% of sample projects. In the remaining 28% projects, WMGs were also present; however, they were mostly non-functional. This situation has significantly changed as a result of WMIP implementation. By the end of April 2015, around 785 WMGs and 72 WMAs were organized. The number of organized Water Management Organization (WMOs) in the 32 sample projects of BWDB increased to 414 breaking the target by 50%.

8. Contribution of BWDB in the Water Sector

Water sector development trend along with the population boom, especially in a third world country like Bangladesh, has been facing intricate challenges to maintain the life-supporting environment in the nature. BWDB, being the principal agency in the country for the water resources sector, faced the challenges for ensuring water security for the country. This is further exacerbated due to the future uncertainty about the quantum of water due to climate change, salinity in estuarine areas, water pollution in the coastal region, water logging, drainage congestion, acute shortage of surface water in dry season due to upstream withdrawal, while, during wet season, irregular abstraction of groundwater resulting irregular availability of groundwater throughout the country. BWDB also contributed to take actions for coping with natural disasters and climate change, and ensuring water and food security and environmental sustainability.

8.1 Water Security

While the demand for fresh water is increasing day by day everywhere in the world, its supply is decreasing. Therefore, the gap between demand and supply has been ever increasing globally. In this regard, a report recently issued by the World Bank estimated that in Bangladesh, water insecurity would be the biggest threat/ challenge with regard to ensuring its national security as its vulnerabilities come from both internal and external sources. Water availability in Bangladesh is around 90 billion cubic metres (BCM) during the dry season against the demand of about 147 BCM, a shortage of nearly 40 percent, resulting in drought-like situation in large parts of the country. Another big issue of Bangladesh in global scenario is that, it lies in the economic water scarcity zone, as we have enough water, but do not have sufficient infrastructure to manage the water in sustainable manner.

In a comprehensive study conducted by BWDB, among 405 rivers around 275 rivers are dying and 65 rivers almost dead. The depths of water in eighty percent of the rivers fall within the category of shallow depth; which leads to water insecurity. Another study conducted by BIWTA reveals that around 117 rivers are either dead or losing navigability. There are many causes for losing depths by the rivers; such as sedimentation, dumping household and industrial wastes and filth into the rivers. For example, 7,000 small and big industries release effluent (approximately 1.3 million cubic meters per day) into the Dhaka river system. So ensuring water security for the country's citizens is a huge challenge and BWDB has a great responsibility to face such challenges.

As Bangladesh is a lower riparian country, it has to depend on the upper riparian, in this case, India. While one water sharing treaty gives a temporary respite, two ambitious Indian projects may aggravate the environmental set up and destroy the ecosystem of the country.

- The Ganges Water Sharing Treaty signed as a solution to the water-sharing problem between Bangladesh and India. However, it did not work accurately because of fresh water scarcity. Given the faster rate of climate change, the water insecurity in Bangladesh has heightened.
- India's River Linking Project aims to transfer around 175 billion cubic meters of water from its East part to West part. The river linking project will have adverse impact on Bangladesh.
- India's ambitious plan to construct a large number of big hydro-power plants in the GBM basin is a growing concern for Bangladesh. No doubt, it will intensify water insecurity in Bangladesh.

It is obvious that Bangladesh has to go a long way to ensure water security and BWDB has immense role to play here. However, if properly managed and regional cooperative approach is ensured, future water security can be assured in this region. According to the ADB report 2013, Bangladesh has achieved water security index of only 1.4 out of 5.0 (Forum, 2013); which has been measured in terms of household, economic, environmental, urban water supply and resilience to water related disasters. Among the Asian countries Japan has ensured the security index as 3.4, China achieved 2.6 and the neighbouring country India has achieved 1.6 (Figure 8.1).

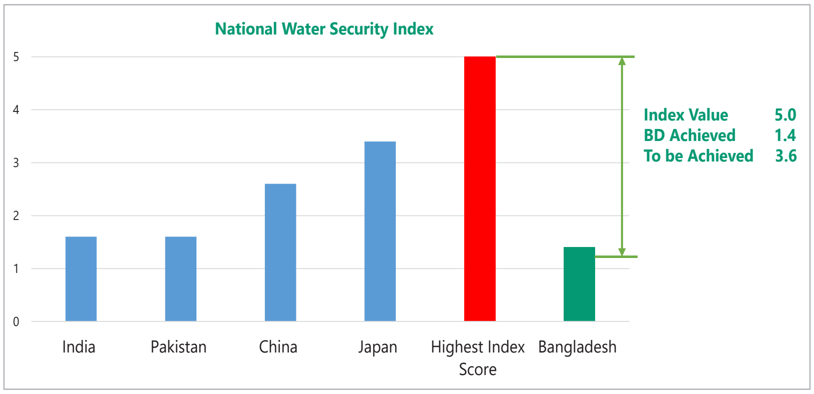


Figure 8.1: National Water Security Outlook Index and goal of Bangladesh

8.2 Food Security

Food security encompasses many issues ranging from food production and distribution to food preferences and health status of individuals. During the 1960s, the focus of FCD projects of BWDB was to protect the crops, mainly Aman, from the river floods as well as tidal floods and that of FCDI projects was to provide supplementary irrigation to Aman and Aus crops. This decade witnessed the introduction of the high yielding variety rice for the first time. Initially, the response of the farmers to it was unenthusiastic. However, due to untiring efforts by BWDB, with assistance from the Department of Agriculture, slowly and steadily, the cropping area under HYV rice was on the rise and during 1970s, this variety became predominant. This was possible because of FCD and FCDI projects by creating an enabling flood-free environment for rice to grow and provide irrigation during Kharif I and II seasons. An overview of pre-project and post-project production of some selected irrigation projects is an example of how the food production increased due to creation of these projects Figure 8.2.

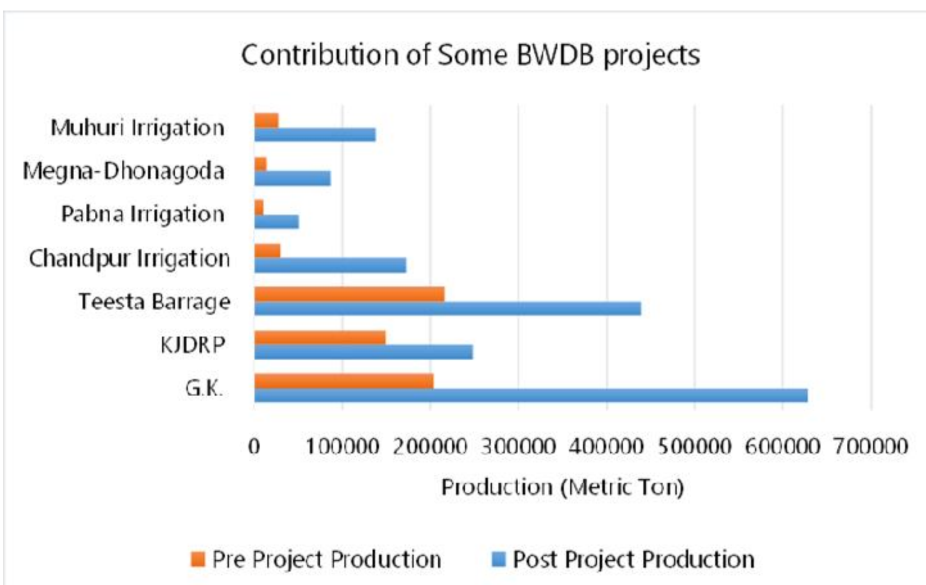


Figure 8.2: Contribution of BWDB projects to enhance food security

Food production is characterized by considerable regional variations, including factors such as tendency to natural disasters, and distribution and quality of agricultural land. So far, a total 6.3 million hectares of agricultural land has been provided with flood control and drainage facilities, thereby facilitating the production of additional food grain amounting to about 6.3 million tons. In addition, 1.6 million ha land in 114 projects has been provided with irrigation facilities and thereby producing about of 2.8 million tons of food grain. The total additional food grain production from the completed FCD and FCDI projects is about 9.1 million tons annually. This additional production is about 25% of the total food grain production of the country. Because of the flood control facilities, the production of Aman crop is on increase as evident from the graph shown in the Figure 8.3. In this connection, rapid rise of High Yield Varity of crops helped to produce more crops for burgeoning population.

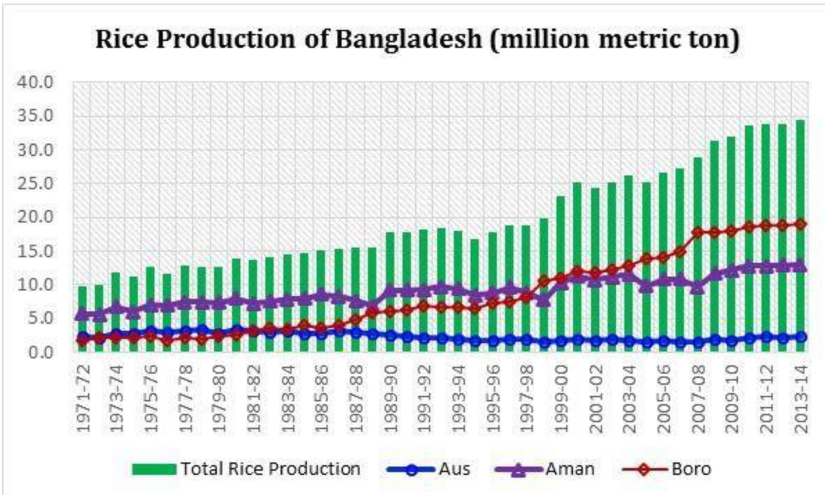


Figure 8.3: Graph showing the gradual increase of rice production (1971-2014)

The FCD(I) projects might led to the reduction of the area for fish movement and grazing, obstruction to routes for shrimp and wintering migration, conversion of seasonal flood plains into paddy land, drying up of beels etc. This may drastically reduce the fish production capacity of beels and floodplains within the project area. The submersible embankments delay flooding up to the mid-May. This delay obstructs spawning migration of fish species like carps from the beels into the rivers during April-May period for breeding, as a result natural regeneration and reproduction is affected.

There is a common perception that FCD and FCDI projects affected the fish production. But the reduction of fish cannot be solely attributed to FCD and FCDI projects alone. There are many other reasons, such as drying up of beels and water bodies by pumps for irrigation, silting up of rivers and khals and water bodies, indiscriminate fishing by drying up water bodies, fishing during spawning period, obstructing fish migration through constructing rural roads, etc. However, BWDB took some measures to offset adverse impacts of FCDI projects on fisheries. During 1980s, FCD and FCDI projects opened opportunities to develop culture fisheries within project areas, which have grown manifolds over the years.

In late 1990s, the borrow pits and canals within FCD and FCDI projects were re-excavated under 'Food for Works' program for the community based culture fisheries. In the later part of 1990s, the country's first Fish Pass project was established in the Manu River Project at Kasimpur for allowing fish to migrate from the Kushiyara River to Kawadhighi haor. Another fish pass was constructed at Sariakandi to allow fish to migrate from the Jamuna to the floodplains. Under FAP initiated CPP project in Tangail, fish friendly structures were built. Later, these initiatives were adopted in many other projects.

The coastal polders have also opened up the opportunity for shrimp culture. BWDB was involved in shrimp culture programs undertaken by the Department of Fisheries. During the period from 1985 to 1992, the IDA-aided Shrimp Culture Project was implemented in the coastal polders. In Khulna, an area of 1430 ha was developed under Polder 20 and 20/1 while in Cox's Bazar an area of 5594 ha under Polder 66/3, 66/4 and 70 was developed. The polder infrastructure were modified and built for introducing salt water within these polders. During 1994-1999, under IDA-aided the Third Fisheries Project, an area of 10454 ha of privately owned land was brought under shrimp culture by constructing 150 new structures in Polders no 5, 23, 31 and 32 in Khulna and Satkhira. In polder 23, an area of 3824 ha was developed as an area which was suitable for shrimp culture alternating with paddy cultivation within the same year. In polder 5, high intensity type shrimp culture could be practiced for a 9-month period and therefore an area of 1686 ha was developed for the purpose.

During 2000-06, IDA-aided Fourth Fisheries Project was implemented. This project was a community based fisheries project working in the coastal polder areas seeking to promote sustainable growth in fish shrimp production. The project activities included setting up of fish sanctuaries, habitat restoration through re-excavation of canals and beels, and construction of fish passes and fish friendly regulators to ease river-floodplain migration of fish.

Lately, BWDB's activities with regard to fisheries development have contributed positively in the growth of fisheries production. In 1983-84, the total fish production was around 0.8 million ton, while in 2013-14, it reached to around 3.6 million tons. From Figure 8.4, it is observed that the production of culture is increasing, however, the production of capture fish is decreasing as the quantity of open water bodies are shrinking because of sharp rise in pollution of water bodies and rivers by industrial and household wastes.

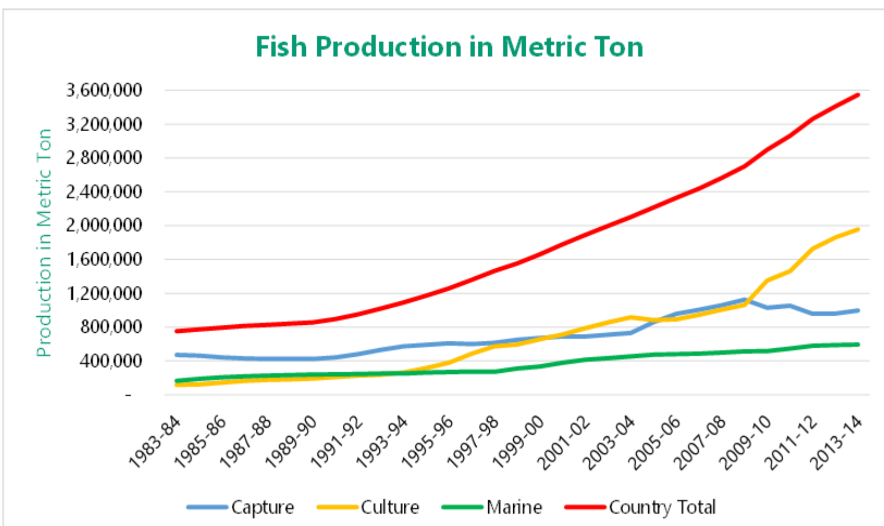


Figure 8.4: Figure showing the increasing trend of fish production, FRSS, DoF (1983-2014)

8.3 Environmental Sustainability

BWDB adopted protection of the natural environment as its own goal to be achieved and is committed to follow directives contained in the National Policies. According to the strategic action plan of BWDB, biodiversity is one of the major challenges in water sector (BWDB, Five Year Strategic Plan of BWDB Roadmap for realizing Organizaitonal goals, 2009). The performance of some BWDB projects regarding the environmental sustainability is briefly discussed in this section.

World Bank (1998) evaluated the performance of one of the projects of BWDB titled "System Rehabilitation Project" in maintaining environmental sustainability. The WB suggests that "there are issues in the fields of wetlands and aquatic ecosystems which have not been taken into account in the planning of either the specific interventions made or the consequences on local land-use patterns, hydrology and ecosystems of these interventions". In particular, during the last few years of the project and because of demands by the affected community and the WB insistence, major structures are now routinely equipped with fish or boat passes to restore fish migrating routes and navigation (WorldBank).

Asian Development Bank (ADB 2005) evaluated the IPSWAM project had remarkable positive changes in case of indicators such as land productivity, fish availability, tree plantation, number of livestock, poultry and human disease (EKN, 2011). Another report from *Community Partnership for Sustainable Water Management, Volume 5* stated that, the original BWDB project had created a tendency among people to remove vegetation from many of the water bodies and use these for culture fisheries. The vegetation or the lack of it has directly impacted the wetland-dependent flora and fauna which led to vulnerability in the environment and thus impacted sustainable development.

8.4 Adaptation to Disaster Management and Climate Change

People in Bangladesh have adapted over generations to the risk of floods, droughts, and cyclones. In areas where inundation is a risk, they raise their houses on mounds, above the flood levels to take advantage of the floodwaters. Farmers in all parts of the country adapt to local flooding and rainfall patterns by growing a range of indigenous and high-yielding varieties of rice and other crops. Rural roads, paths, tracks and other infrastructure such as schools are also raised above flood level, where possible. The combination of frequent natural disasters, high population density, poor infrastructure and low resilience to economic shocks, make Bangladesh especially vulnerable to climatic risks. The high incidence of poverty and heavy reliance on agriculture and natural resources increase their vulnerability to climate change.

The direct annual cost of the national economy due to natural disasters over the last 10 years (damage and lost production) is estimated to be between 0.5% and 1% of GDP. As the economy grows, these costs are likely to increase in absolute terms and as a proportion of GDP, if the climate change impact is not included into long-term economic planning (MoE, 2009).

The GoB is always remaining vigilant and taking proper steps to combat the adverse impacts of natural disasters. Since 1970s', the government, with the support of development partners, has invested in the following sectors to fight against natural disasters:

- Flood management projects to raise the agricultural productivity in 6.3 million ha under flood protection of low-lying rural areas and to protect them from extremely damaging floods;
- Flood protection and drainage projects to protect urban areas from rainwater and river flooding during monsoon season;
- Coastal embankment projects, involving over 6000 km of embankments and polders, designed to raise agricultural productivity in coastal areas by preventing tidal flooding and intrusion of saline water;
- Comprehensive disaster management projects, involving community-based programs and early warning systems for floods and cyclones;
- Irrigation projects to enable farmers to grow a dry season rice crop in areas subject to heavy monsoon flooding and drought-prone areas in other parts of the country;
- Coastal 'greenbelt' projects, involving mangrove planting along nearly 710 km of shoreline.

These investments in climate proofing the country have had a major impact on *economic growth and poverty reduction*. Average annual food grain production in Bangladesh has grown from about 9 million in the mid 1970's to over 35 million metric tons today, which has raised rural income and created jobs for the poor people in agriculture and related sectors, and made the country largely food secure. Over the last 10-15 years, the number of fatalities from natural disasters has declined, as the country's ability to manage risks, especially floods and cyclones, has improved and community based systems have been put in place.

8.5 Financial Involvement

Poverty is the country's most disquieting socio-economic issue that needs immediate attention. The number of people living below poverty line is gradually coming down (58% in 1991 and 22.5% in 2015) Economic development is also one of most important strategic goals of BWDB. The year-wise break-up expenditures and number of projects taken up for implementation show that the number of projects being implemented by BWDB is on increase. These projects are located mostly in the rural areas benefitting the local populace, thus in the process, strengthening the rural economy. This ultimately helps in reducing the rural poverty by securing assets and generating employment (Figure 8.5).

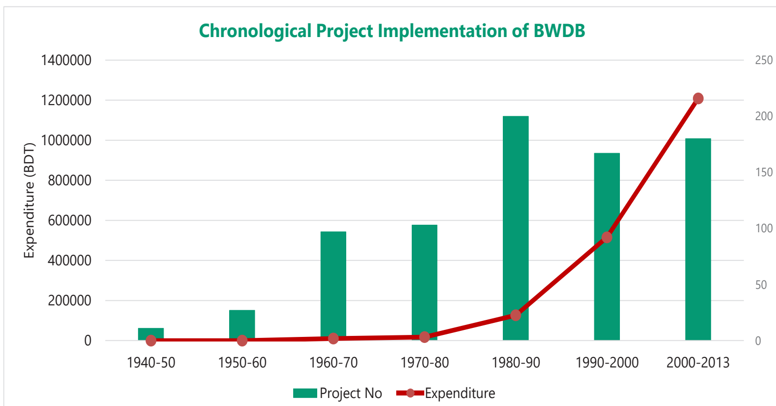


Figure 8.5: Project implementation trend from 1940-2010 (Source: BWDB, 2015)

The benefits accrued by water development projects are multifarious, increasing both the agricultural and fish production. There are other positive impacts i.e. embankment serving as roads providing micro-trading facilities, bringing qualitative changes in ecology, supporting community mobilization, linking with national level programs and accelerating infrastructural growth of all other sectors such as health, education, and food. The flood-free environment has also contributed to the accelerated development of the industrial sector.

8.6 Operation and Maintenance (O&M)

In the BWDB Act 1972, the main focus was on the development of water resource projects throughout the country in order to take care of the issues regarding flood control, drainage and irrigation management. But, later it was observed that only infrastructure development was not adequate to support water resources management; proper attention must be given to the operation and maintenance (O&M) also. In order to address these concerns, the BWDB Act 2000 emphasizes on the O&M of the water resources projects in parallel to the development. According to the Act the main mandate of BWDB is to operate and maintain the completed projects, excavate or re-excavate the drainage channels, khals and waterways for facilitating the irrigation, fish cultivation, navigation, wild life preservation and sustainability of environment.

8.6.1 *Operation and Maintenance (O&M) of infrastructure*

For proper operation and maintenance of the water resources infrastructures, the following matters are mostly considered.

Maintenance of hydraulic structures: The hydraulic structures such as barrage, regulator, sluice, pump etc. have been damaging due to high usage and natural disasters, which need to repair regularly. The maintenance works include the following activities:

- Repair of main body of the hydraulic structures
- Protection of physical environment
- Service and supply for structure operation

Maintenance Dredging and Excavation of canal: The river channels and khals carry around 1 billion metric ton of sediment every year; one-third of its deposits on channel bed and floodplains. So, for proper maintenance of the channels these require regular dredging and excavation of the channels.

Maintenance of Irrigation Canal: Irrigation canals are nothing but earthwork constructions, and as such, very much susceptible to damage. These canals require lot of maintenance, upkeep and watch as to ensure continuous and efficient functioning. Various problems are posed by the irrigation canals during their use, and as such need constant attention, for: (i) silting of canals; (ii) weed and plant growth and failure of weaker banks; and (iii) canal breaches due to piping, overflowing of canal, etc.

Maintenance of Embankments: Sometimes local soil is used to construct the embankments to minimize the cost, which may not be suitable for embankment; because if it were not water-resistant, it would cause seepage of water. Eventually, the strong pressures of seepage water, mainly during high flood, make the embankments weaker and finally cause embankment breaching. So, regular maintenance of the embankments is necessary. In addition, the embankments need to be reconstructed in every 5-10 years considering the location and usage. Another point is to be mentioned here that, during river erosion the embankments need to be protected, the cost of which should be considered as flood embankment maintenance cost.

Maintenance of Submersible Embankments: The submersible embankments in the haor region deteriorate in the monsoon as those remain under water. In addition, the temporary embankments, which are constructed to protect boro rice, are demolished by local stakeholders in order to ensure fish breeding and navigation of local boats. For these reasons, the submersible embankments and cross dams and khals need to be maintained and reconstructed every year.

8.6.2 *Food for Work (FFW)*

World Food Programme (WFP) executed various projects in Bangladesh since 1974, by providing food for work, including development of rural and water management infrastructure. With WFP support poor people could improve nutrition and skills through building of infrastructure such as roads, embankments and irrigation canals under different Govt departments. BWDB also undertook a number of interventions using the food-assisted programme with support from the WFP, in order to supplement regular O&M of more than 600 completed projects and schemes. The food-supported programme of the BWDB was initiated during 1974-75 through the office named as "Central Flood Control Cell," which was renamed as Food for Work (FFW) during the late 1980's.

The Food/Taka for Work project was implemented by following the 'Guideline for Project Planning and Implementation under the River/Khal Re-excavation (cluster) Project for 2005'. All activities under FFW/TFW mainly focused on generating income of the rural poor through creation of employment opportunity with participation of all stakeholders of the project area. It also provided water management and irrigation facilities, enhanced system conveyance capacity and promoted water conservation activities which ultimately aimed to improve agricultural production as well as livelihood condition of the rural poor of the project area. A total of 6112 schemes in about more than 600 BWDB completed projects were executed by FFW/TFW during implementation period of 2000-2001 to 2006-2007.

A total of 6112 schemes in about more than 600 BWDB completed projects were executed during the implementation period of 2000-2001 to 2006-2007. The major components of the project included 5200 km of river/khal re-excavation and rehabilitation of 6000 km of embankment/road. The local people were found to be satisfied with the FFW/TFW activities. Their direct involvement in the FFW/TFW earthwork played a big role in alleviating poverty by increasing employment opportunity and agricultural production. All work at the local level was completed by the project implementation committee that was formed following the guideline for the implementation of the scheme selection work for FFW/TFW.

Though the FFW/TFW Project was claimed to be carried out with necessary transparency, there was reportedly widespread corruption claimed by various news media in the country. The media claimed that there was a chain of corruption involving all tyres of administration and public representation. Nevertheless, after completion of the project in 2007, the important infrastructure were reported be more vulnerable to frequent hazards, e.g. floods, salinity and siltation, and the cost of O&M became comparatively higher for those projects.

8.6.3 *Functions of BWDB O&M*

The main function of Operation & Maintenance is to repair and maintain the hydraulic structures, routinely and also during the times of natural disasters or in emergency. The overall functions of O&M are described below:

- Preparing and updating of inventory of completed projects containing all basic project information
- Operation and maintenance of completed projects over 5000 ha as outlined in the NWPo
- Providing management guidelines and necessary assistance to local and community organizations and the local governments for O&M of projects with command area below 5000 ha
- Rehabilitation of projects under GOB funding and as directed by the Board from time to time
- Water management activities as indicated in the NWPo
- Cost recovery, command area development and matters related to participatory water management
- Preventive works to anticipated damage to hydraulic structures due to natural disasters, damage assessment and emergency repairs following natural disasters.

8.6.4 *Funding of O&M*

In order to keep the existing infrastructures running smoothly, substantial fund is required for O&M. The GoB allocates the O&M fund every year, which is inadequate and fails to meet the O&M activities each year. The proportion of fund demand and availability is shown in Figure 8.6.

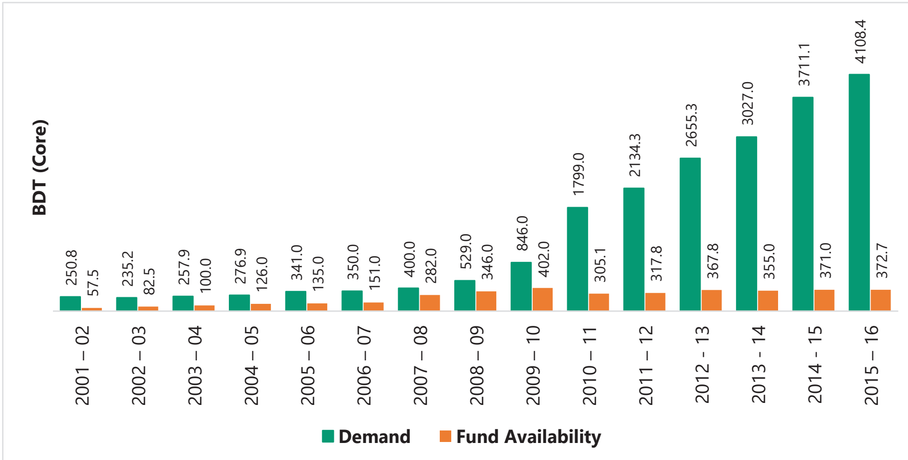


Figure 8.6: O&M Demand and Fund Availability of BWDB

Observation: Over the years, BWDB has developed a large number of infrastructures across the country. These infrastructures need regular monitoring, adequate operation and maintenance to keep them functional. The earthen embankments are eroded by wind and rainfall, human intervention as well as animal grazing. Drainage channels are recurrently silted up during monsoons and floods, requiring maintenance excavation every year. The sluice gates are corroded regularly due to salinity and other reasons. It is evident that a substantial amount of money is required every year for proper operation and maintenance. From Figure 8.6, it can be clearly seen that BWDB gets only about 10 percent (including establishment expenditure) of its requirement. As a result, most of the maintenance works suffer due to lack of resources. Consequently, the cost of repair works keeps rising and the structure gets deteriorated and ultimately needing rehabilitation at a great cost.

A provision should be kept for emergency funding of O&M activities, especially in the coastal region, where, emergency repair and maintenance work may be needed due to sudden breach of embankment. If the repair is not done immediately, the amount of loss would be substantial, and the cost of repair later would be a few times higher than the original cost.

Another important aspect is that in many places the embankments are eroded by the shifting of rivers. Because of non-availability of resources, the bank erosion cannot be prevented in time. As a result the eroded embankments have to be relocated, requiring fresh land acquisition and resources.

As a result of non-availability of resources the structures cannot be maintained consistently and thus inadequate O&M has become a perennial problem in almost all projects. Gradually the structures deteriorate and after a period of time, the project needs total rehabilitation at a high cost. If O&M fund could be available in time, the rehabilitation of the projects would not have been required.

9. Lessons Learnt

Numerous projects under the water resources sector have been carried out during the last six decades. While some projects were successful, others did not meet desired results. However, the overall progress is worthwhile. The crop production increased manifolds, and the containment of flood is much better organised than before. One cannot control the natural disasters like floods, draughts, cyclones, storm surges, etc., but due to the implementation of these projects, the mitigation process improved a lot, and today, more areas are brought under irrigation, more areas are flood-free, more people could be evacuated and taken to safe shelters during the devastation of natural disasters.

Despite all these efforts, nature keeps playing havoc with life and property of the people in this country. With the passage of time, one can only hope that the situation may be improved by carrying out tangible and purposeful projects in near and far future. However, many planning and design considerations need to be changed for better performance of the projects. The planning, design, implementation as well as operation and maintenance of these projects are very challenging. The experiences gathered from the projects are diverse and valuable, and will be used as references for future. This Chapter presents a summary of the lessons learnt from the development in the water resources by BWDB and other agencies based on secondary data, literature review, and individual perception of the performance of these projects. The sections have been compiled based on flood management, erosion control, irrigation management, drainage improvement, urban protection and participatory water management.

9.1 Flood Management

Flood management means to take measures or develop some methods to prevent, avoid, minimize or reduce the impact of floods. Such measures could be structural or non-structural, although the prudent approach is to have a combination of two types of measures. However, since 1960, different consulting firms under BWDB have carried out a number of studies and projects. Overall performance of those studies and projects are satisfactory. The lessons learnt from the projects are listed below:

1. Complete flood protection in Bangladesh is neither feasible nor possible, given the multi hazard scenario and economic condition of the country; hence it should not be targeted.
2. In FCD/I projects, the gravity drainage is only possible if the outside river stage is lower than the water level within the project area. If the outside level is equal or higher, drainage must be done by pumps. Providing full flood protection to a certain extent is only possible in the FCD/I projects equipped with pump drainage facilities.
3. FCD/I projects offer flood protection by embankments which are designed with a certain return period of floods, but in case of extreme floods accompanied with intense rainfall, the embankments are liable to inundation. Same point as below
4. The embankments under the FCD/I projects, mainly located in the rural areas to protect agricultural lands, are normally designed for 1 in 25 years return-period floods, whereas, the embankments located on the banks of major rivers are designed for 1 in 50 years return-period. During the occurrence of higher frequency floods, these infrastructures as well as the project areas are threatened to flooding, if an embankment breaches. Poor and inadequate maintenance of the embankments has been a serious constraint in providing benefits of flood protection in embanked areas. Thus the designed flood risk-level should be dependent on the value of assets within the project area and the cost involved. Obviously, the project cost increases with the increased level of flood protection.
5. Submersible embankments have been constructed for the flood protection projects in deeply flooded haor areas or in similar low-lying beel areas in Chalanbeel and Goplaganj to ensure a safe harvest period for the winter rice crops like Boro. The submersible embankments are usually designed for 5 or 10 years return period only for providing partial flood protection to the Boro crops up to the middle of month May. Later, these embankments are used as fish grazing. Hence, full flood protection is neither advisable nor desirable considering the technical, economic and environmental aspects of this region.
6. The sea-facing embankments are designed for 1 in 100-year return-period to withstand overtopping against storm surges. In other places of coastal polders, the river-embankments were initially designed for a return period of 1 in 25 year, which later redesigned as considering 1 in 50 year, under the Coastal Embankment

Improvement Project (CEIP). The cost involved for higher level of protection is not justifiable on the asset values. However, flood protection level of the embankments around seaports and economically important areas may be increased depending on the value of assets to be protected.

7. Under the Secondary Towns Integrated Flood Protection (STIFF) Project, the towns were to be protected for floods of a return period of 1 in 100 year. Subsequently, this level of flood safety requirement was considered economically unfeasible and lowered to 1 in 50 year return period. It illustrates that providing high level of safety may not always be attractive from economic point of view.

8. The machine-compacted earthen embankments have proved to be better flood protection than manually compacted embankments. It was observed that in projects like CIP, MDIP, PIRDP, DND, NNIP, etc. the safety was ensured against high frequency floods of 1988, 1998 and 2004 by the embankments constructed with mechanically compacted soil.

9. In addition to provide flood control facilities, the embankments under the FCD/I projects are facilitated with multipurpose services, such as being used as rural roads, flood shelters during floods, plantation in the embankment slopes; the borrow pits used as fish culture and drinking water in arsenic-laden areas, etc. So these facilities can be enhanced further while taking new projects in future.

10. The maintenance of the submersible embankments is always a big issue. During the monsoon, these embankments are damaged by wave action or manually cut for fishing and navigation. Earlier experiences show that in Sylhet haors, the floodwater recedes completely by December and the flash flood hits by early April. So, the repairing and maintenance works should be carried out during the dry season (December – March) of each year. Therefore, a proper financial management system, with administrative authority at field level, should be ensured for the haor areas.

11. The earthen embankments are normally damaged by many natural reasons such as severe rainfall, winds, wave attacks, and man-made reasons like vehicular traffic, unauthorised human settlements on the crest and side slopes of the embankments, rats, foxes etc. So considering the importance of embankments in particular areas and risks of its frequent breaching, provisions should be kept in annual O&M budget for repairing and maintenance after each monsoon season.

12. As some embankments are occupied by the people, both the crest and its side slopes, the embankments of the occupied portion cannot be maintained as per design requirement. As such, all unauthorised squatters on the embankments have to removed/ rehabilitated elsewhere before the embankment repaired. However, this task often proves to be difficult, resulting in poor maintenance and weak embankments.

13. Flood damage could be reduced largely, if flood-related real-time data from the upstream areas were available for flood forecasting.

14. FCD/I projects have reduced the area of capture fisheries and restricted the unhindered movement of fish. However, these have opened up the possibilities of extensive culture fishery in the flood protected land. Fish sanctuaries may be developed and maintained in suitable locations within the project areas.

15. The performance of fish passes made under the Manu Irrigation Project at Kashimpur and the Brahmaputra Right Embankment project at Sariakandi have shown much positive results. Thus provisions for fish passes may be encouraged and provided in suitable locations during implementation of future projects.

16. Due to resource constraints for O&M of FCDI projects, the operation of regulators, sluices and other hydraulic structures in most of the project locations are in poor condition.

17. Food for Work (FFW) programs had both the positive and negative impacts. The project ensured the maintenance of the flood embankments as its positive impact, which on the other hand, had destroyed the capacity of water management institutions in the activities for maintenance of embankments, counted as its negative impact on water resources sector.

18. Drainage of excess water is an integral part of any flood control/ protection project. Improvement of channel to facilitate drainage can be done through loop cutting in small meandering rivers and by dredging in particular locations of main channels of large and small rivers to maintain its navigability during dry period. However, dredging is a costly operation and not economically feasible for large rivers like Jamuna but can be taken into account as temporary solution in critical locations to ease the flow of the flood water as well as keep the inland navigation routes open.
19. Over the years, the FCDI projects had integrated with only the physical environment whereas the social and economic needs have undergone many changes. Throughout the country, the settlements are expanding in active floodplains, the growth centres are being built and extended; construction of the roads and bridges is continuous for increased accessibility, and thereby, the drainage pattern are interfered with. Moreover, the climate change impact has become more visible. Considering these aspects, the time has come to revisit all the existing FCDI projects to make them holistic and more functional.
20. Flood forecasting and warning is one of the most effective non-structural methods for flood management and mitigation. Since 93% of the GBM catchment area lies outside Bangladesh, flood forecasting and warning in our country cannot be fully effective without regional cooperation in data exchange among the co-riparian countries (India, Nepal and Bhutan). In order to make it more functional, water level and rainfall data sharing from upstream points of India should be ensured.
21. The concept of flood proofing and floodplain zoning in not much practiced in our country until date. However, these non-structural methods of flood mitigation can be fruitful to facilitate development in much organized way as well avoiding huge investments for flood prone areas, if proper planning and land development rules could be formulated.

9.2 Irrigation Management

Irrigation is an important input for growing crops, practised by Bangladeshi farmers to intensify crop production during dry period. At present, 52.6% of the total agricultural land is under irrigation system. The public sector projects mostly utilize surface water and the irrigation facilities are being provided to 1.6 million ha of land throughout the country. Overall performance of the public irrigation projects is satisfactory. The lessons learnt from the irrigation projects are listed below:

1. Use of traditional methods by simple manual devices accounts for only 5% of the net cropped area while modern methods (tube wells and power pumps) are used in 95% of the cropped area.
2. The performance of public sector irrigation projects are mixed; the performance of large barrage projects are better than the medium and small pumped irrigation projects both in terms of productivity and O&M cost.
3. The pumped irrigation projects largely depend on the availability of electricity; the erratic supply of electricity disrupts the irrigation schedule.
4. Irrigation service charges realized by BWDB is not sufficient to cover the O&M costs.
5. Farmers prefer surface water irrigation to ground water irrigation, because surface water contains sediments and nutrients, which in turn, enrich soils and increase productivity. The groundwater irrigation overtook and rapidly expanded in the irrigation sector after mid 60s' and now encouraged by the private sectors only. The groundwater tables are depleting due to unplanned ground water abstraction, which might restrict ground water irrigation in future.
6. The irrigation canals are mostly unlined, allow large water loss from seepage and percolation. In order to reduce wastage and conserve water, the technology termed "Alternative wetting and drying" can be promoted to farmers to use water effectively and reduce groundwater depletion.

7. Use of fertilizers by the farmers are often disrupted by improper distribution from government and inefficient management practices. Presently the farmers are being encouraged to reduce the usage of chemical fertilizers and instead, practice organic farming.
8. The level of the stakeholders' participation in the management of the irrigation projects is found to be weak; the interaction between the officials and the stakeholders should be held regularly.
9. The water management, an integral part of the irrigation projects, is very complex and requires intense involvement of policy makers and stakeholders. Due to reduction of staff, the quality of services by the department at present has deteriorated. So necessary manpower along with adequate fund for O&M should be ensured for proper management and functioning of the projects.

9.3 River Management

Bangladesh has more than 405 rivers, acting as a lifeline of the country. Therefore, the river management is very important. The purpose of river management is to carry transboundary flows to the Bay of Bengal, protect the riverbanks from erosion (urban centres, bridges, important infrastructure, growth centres, heritage sites etc.) and to facilitate navigation. So far, the rivers are being managed in piecemeal basis, in form of erosion control, without taking an integral view of the whole river systems of the country.

From the past experiences, it is evident that, the task of bank protection is highly challenging in terms of planning, design, execution as well as operation and maintenance. There are many instances of failure or damage of bank revetment, hard points, groynes and spurs. The lessons learnt from these achievements and failures are summarised below:

1. The revetments, groynes or spurs constructed in minor and medium rivers, having predominantly single channels, are functioning satisfactorily with relatively low maintenance cost. The performance of hard points, bank revetments, groynes or spurs constructed in large braided or meandering rivers like the Brahmaputra/Jamuna, the Ganges, the Padma and the Meghna rivers has been relatively poor. In some cases, maintenance and repair costs of spurs and groynes often substantially exceeding initial capital costs.
2. The failure or damage of bank protection and river training works are attributed to:
   (a) Improper site selection, due to shifting of locations of erosion attack
   (b) Improper or no investigation of sub-soil materials
   (c) Improper type of construction methods and construction materials
   (d) Lack of regular monitoring of morphological changes (sedimentation, erosion, etc.)
   (e) Lack of regular monitoring of the structures and timely repair, maintenance and adaptation
   (f) Lack of funding within the required time-frame
   (g) Outflanking of the river stream, due to inadequate protection measures
   (h) Improper design or adaptation after damages due to lack of damage monitoring and/or understanding of reach-scale morphological behaviour of the rivers, hydrodynamic forces and soil properties.
3. The experiences from FAP 21/22 study have demonstrated that guiding revetments and adaptive riverbank protection programs can be successfully implemented at considerably reduced costs.
4. Sirajganj Hard point had some small portion damaged in 2009, 2010, 2011 and 2014. Each time, different sites were affected. The reason was found to be linked with the formation of island/cluster of islands in the river which deflect the flow towards the protection works. It was also found that formation of scour, was primarily due to changes in the channel alignment and shape of the chars. The shifting of thalweg at the vicinity of the training works and development of scour hole initiated the failure of armours of the hard point. It is also believed that construction of the protective apron did not follow strictly the design guidelines.

5. The failure of groyne structures can generally be related to scour processes and outflanking of the river stream that might have caused severe erosion at the structure locations. This phenomenon has been observed at nearly every groyne along the Jamuna River. Due to complex river planform, rehabilitation or reconstruction of the structures may not serve the purpose. The main reasons for recent failures of RCC spurs in the Jamuna were the parallel flow along the under-designed earthen shank and undermining or underflow at the middle part of the RCC head.
6. The embayment at the upstream end of Sirajganj, Kalitola, and Guthail hard points demonstrate clearly that for an efficient and sustainable bank protection, long reaches of bank have to be protected in order to provide an additional safeguard against outflanking.
7. Bank protectives on medium rivers are more stable and require relatively low maintenance cost. Bank protectives on major rivers (Jamuna, Ganges, Padma, Meghna) are less stable with high O&M costs (sometime higher than initial capital costs). Similarly, the dredging of the medium and the small rivers is more effective and easier than the major rivers.
8. Every river has its own hydro-morphological behaviour, which has to be understood properly through research before taking any river management project.
9. In the past, river protective measures were done on piece-meal basis and site-specific, based on shallow perspectives. Since last decade, time-series satellite image-driven researches enhanced the knowledge of morphological understanding of the rivers and proved to be much more effective than earlier studies.
10. The river management work along the major rivers should be implemented within a scheduled time-frame, otherwise the investment may be wasted as the river planform and flow pattern may change abruptly within a certain period.
11. The present practice of preparing DPP is too rigid, specifying the locations and time frame. Often, a long time is taken from the formulation of a project to its execution. By the time, the project is executed; the overall planform of the river might have changed. Therefore, a fixed framework of DPP may be prepared for executing projects of river training works, especially, in case of large rivers.
12. The bank protective works with geo-textile proved to be effective and cheaper alternatives to concrete blocks.
13. The Tidal River Management increases drainage capacity of river through scouring in the river beds and maintaining the river navigability and thus removes water-logging along the rivers of south-western region of the country.
14. Integrated master plan based on enhanced understanding of river morphology is of top priority for the river management sector.

River management through dredging

The lesson learnt from the Gorai Restoration Pilot Dredging Project is that the flow of the river could be restored by dredging; however, its sustainability will depend on the maintenance dredging each year. Long-time annual maintenance budget should be an essential component of project formulation. Nonetheless, the construction of the Ganges Barrage Project remains the permanent solution to supply water to the Gorai River.

Jamuna River Dredging (2010) at Sirajganj was a pilot dredging scheme, limited to a length of only 20 km and having bed width of 120 m. being a pilot dredging case; its sustainability remained to be ascertained. However, this pilot project has generated a good number of data/information and some experiences based knowledge for implementation of large scale dredging activities in future. The lessons learnt from this experience do not constitute a complete picture of metamorphosis of the Jamuna during/after the dredging operation. The lessons learnt from implementing the pilot dredging project are as follows:

1. The anabranch of the Jamuna can be closed and the diversion of flow is possible by constructing sufficiently strong cross-dams;
2. The construction of some cross-dams and bank protection works, and intelligent/adaptive dredging in well-planned manner would give better result, the dredging will help stabilize the river;
3. Careful planning is needed for the dumping of dredged material;
4. The dredging alignments should be fixed up by simulation of backed up field survey data, for better performance of dredging;
5. Continuous monitoring is needed; guiding flow through a channel would be suitable for the river.
6. Integrated river management with strategic dredging and revetment with embankments improves drainage capacity of the main channels of the river.

9.4 Protection of Urban Areas

The town protection works have improved the property values around the project sites by providing a flood-free and secured living environment. In an ADB study (Project performance audit report on secondary towns integrated flood protection project, STIFPP 2003), it is found that the property values rose to 20 -40% in Kurigram, 20 -80% in Maulvibazar, and 50 -100% in Panchagarh, because of improved town protection activities. Improvements in the living environment were reported by 51% of the respondents in Khulna, 63% in Kurigram, 83% in Maulvibazar, and more than 95% in the remaining towns. Other slum improvements also have provided a greater sense of security and permanence within the towns. As such, the protection of urban areas in the country should be regularly done and new township projects can be taken into account in future.

9.5 Participatory Water Management

Participatory Water Management (PWM, described in detail in Section 7.9), forms an integral part of water resources development, which was not realised until many water development projects malfunctioned or failed to meet local people's aspirations. The peoples' participation concept would not work smoothly unless there is a good understanding and coordination between the implementing agencies and the local people. The 'Chasi' (Farmers) Club was formed in G. K. Project during 1960s in order to involve the farmers in water management. Later, the peoples' participation in some water resources projects, especially the donor-aided projects, was utilized as early as 1970s' and 1980s'; examples: Early Implementation Project (EIP) and Delta Development Project (DDP), funded by the Netherlands. For EIP, the initial contribution of the Netherlands Government was to support relatively small labour-intensive, quick yielding water sector projects through BWDB. The project had mainly a rehabilitation and relief character; and the main objectives were increased agricultural production and generation of employment for unskilled labours during lean season. The Delta Development Project, aimed at the rehabilitation of Polders in the Ganges Delta (Polder 22 and 29) with special attention to sustainability, was implemented during 1981-1991.

Another project of that period, namely Land Reclamation Project (LRP, 1977-1991), which was aimed at promoting a quicker and more effective use of newly gained lands, so that food production could be increased and the conditions of poor farmers be improved. This project organized landless farmers, and trained them for taking care of the O&M of the polder on newly accreted land; the farmers were provided *khas* land in the polder, and thus the community settled there afresh successfully. The project was an example of the peoples' participation in the community based water management and water governance.

Water Management Improvement Project (WMIP), South-West Area Integrated Water Resources Planning and Management Project (SWAIWRPMP), Integrated Planning for Sustainable Water Management (IPSWAM) are some of the other projects where participatory water management was intensely followed. These projects increased the water management and water association groups to a substantially high number; it also involved participation of high percentage of farmers and a good number of women.

However, in projects like Khulna Jessore Drainage Rehabilitation Project (KJDRP), the desired participation by the people didn't happen until the Tidal River Management (TRM) methodology was applied in the mid-1990s', where a community based approach was adopted. The community was involved in finalizing the design of the drainage structures and canal networks, and the WMOs actively participated in the construction of perimeter embankments in some places. This is a good example of how a project can deliver the output in an efficient way when the peoples got involved in the projects.

As seen from the above narration, many projects yielded benefits by following the guidelines for peoples' participation during the last two/ three decades. A good lesson is to be learnt from the examples of these projects. Some observations on participatory water management are given below:

1. The people's participation in the water management projects is a half-hearted approach, lacking in proper motivation.
2. The community participation, which is the key to the sustainable management of the FCDI projects, could not bring full output due to lack of effective participation of the stakeholders in planning, design and implementation of projects. There was even lacking in taking proper responsibilities for future activities of operation and maintenance works.
3. The Guidelines for Participatory Water Management (GPWM), formulated in 2000, was applicable to all FCDI projects of BWDB & LGED. However, this guideline superseded the Guidelines for People's Participatory (GPP), which was only applicable to BWDB's irrigation projects.
4. The financial accountability for all WMOs are yet to be established resulting in poor accountability and transparency. Some reasons are identified as dormant or non-functional accounts; unwillingness of community members to contribute to the cost of water management operations; lack of official record of bank accounts and the maintenance activities; unilateral financial decisions rather than consensus between executive members of WMOs, lack of access to systematic technical information; no formal mode of communication, etc. The practice of Participatory Water Management was also hampered by the inadequate funding and misallocation of the approved funding.
5. The Government has formulated the Participatory Water Management Rule in 2014. The complete implementation of this rule will ensure better functioning of WMOs and thus the people's participation in the water management projects will significantly improve.
6. Involvement of BWDB officials is deficient in supporting WMOs' functioning right from the beginning of the project cycle i.e. planning, design, implementation and O&M. This is one of the reasons for poor management performance of WMOs. So PWM should be listed as one of the core activities of BWDB.
7. BWDB staffs are lacking proper training and guidelines for institutional arrangements. One of the main causes of dysfunctional water management groups was the undefined responsibilities of the concerned officials. Moreover, interpersonal skill development should be ensured for both the BWDB officials and WMO members through training.
8. Improper institutional interaction between implementing agencies and local government institutions at Upazila and Union levels is another reason of malfunctioned PWM.

9. This approach was imposed upon the community rather than developing through extensive public consultations, which in result could not stand out effective on real field.
10. Local elites and politically powerful people might have negative influences on the PWM in terms of management and leasing of the khals.
11. Several external factors as mentioned below are the reasons for decreasing community involvement:
    a. WMO formation was done by the external bodies rather than the communities themselves;
    b. Generally weak representation of women, except few projects;
    c. Political influence of landowners and *ghers* (shrimp cultivation areas) on decision-making authority;
    d. Lack of renewal of the executive committees.
12. The long-term sustainability of WMOs depends on the democratic process in the formation of the WMOs as PWM Rule 2014.
13. Technocrats do the present practice of group formation and they lack proper training to deal with human relationships. The group should be formed not only by technical persons but also with the coordination of sociologists, anthropologists etc.

9.6 Ecology and Environment

The context of FCDI projects has undergone dramatic changes during the past half a century. In early stage, the FCDI projects were implemented in order to achieve food sufficiency, but later it has been perceived that these projects also contribute to physical, environmental and social development of the country. Moreover, FCDI projects have become part of the ecological component of the surroundings. These outcome also led to some studies prior to implementation of any development project i.e., Environment Impact Assessment (EIA) and Social Impact Assessment (SIA) and Environmental Management Plan (EMP) for safeguarding the environment as per guideline provided in FAP studies:

1. The recommendations of EIA and SIA studies should include all sorts of bio-diversity and environmental parameters.
2. The assessment of the environmental flow in all rivers is essential to preserve bio-diversity of the river systems. The withdrawal of water from the rivers should consider the environmental flow requirements of the rivers.
3. Mitigation options for arsenic contamination should include development of arsenic free groundwater sources, well-treatment of contaminated water and increase use of surface water sources in order to lessen the burden on groundwater.

9.7 O&M of BWDB Projects

The water sector has witnessed the execution of a large of number of projects over the years and continuing to increase its number year by year. The O&M is an essential component of the project management in order to keep the systems in top operating condition in order to achieve its' required objectives. The maintenance works are of three types: i) routine maintenance ii) periodic maintenance iii) emergency maintenance.

BWDB has two budget-lines: (i) development budget and (ii) non-development budget. The O&M budget is given from the non-development budget, which itself is inadequate to meet the O&M requirements. In fact, a huge sum of money is required every year for O&M, against which only a little amount (less than 10%) is available. It is quite unexpected that the mandate of BWDB, as per BWDB Act 2000, is changed from implementation to O&M,

however, the adequate budget provision is still unavailable. The following provision should be considered for O&M of the projects:

1. The O&M culture is not deeply ingrained in the development culture of the country. Rather than O&M of the existing projects, priority has always been given to the development of new projects. The water sector is not immune to it.
2. The Annual Development Programme (ADP) should have a separate provision for O&M of the existing projects, which would be utilized for O&M and upgradation of the projects.
3. During the project preparation, O&M plans need to be set giving attention to the following simultaneously:
    - Contents development and stakeholders' involvement and governance
    - Feasibility study and implementation
    - Investment planning, financing including O&M
4. O&M manuals need to be prepared for all infrastructure of the water sector projects and project maps should be readily available in respective project offices. This should also clearly state the tasks of the project officials, responsibility for the project management and time-line of the activities.
5. The project officials should be empowered to take actions on emergency repairing works as and when required and clear guidelines should be provided to ensure transparency of the expenditure.
6. A funding for O&M during the construction period should be ensured for the projects of which construction period is more than 3 years.
7. After completion of every project, there should be an Evaluation Report which would indicate the lessons learnt from that project.

10. Conclusion

The main purpose of the report is to present an overall image of the development in water resources sector of the country during the last sixty years and the lessons learnt from the success or failure of those developments. The number of projects carried out during these six decades was significant, but the outputs of many of the projects could not reach the desired levels. One could cite many reasons and loopholes for the lack, but the mistakes and errors must be taken into account while planning and implementing future projects and progressing with new developments. The BDP 2100, while formulating the strategies, would avoid these lapses as far as possible in the future water resources development projects. The strategies need to focus on integrated efforts in new water development endeavours or taking up any large maintenance programs. A better coordination among the relevant public agencies should be in place so that projects do not suffer due to lack of coordination.

The institutional development and the capacity building of the two principal water resources institutions, one for planning WARPO and another for implementation BWDB, need immediate attention. WARPO is expected to play a vital role as a national macro level Water resources planning institution, however, because of its inadequate institutional capacity and expertise, they are yet to establish itself as a premier planning institution in water sector. Similarly, WARPO is yet to develop itself as a pioneer institution to coordinate water sector agencies like BWDB, LGED, DPHE, WASAs, etc. because of inadequate technical and financial resources. How the organization would put up itself as the top coordinating agent, as outlined in the National Water Management Plan (NWMP), when the organizational structure remains visibly inadequate itself as well as lacking of financial resources? NWMP consumed more than US $ 20 million in preparation but it could not be updated even for once in a period of 12 years (from 2004 to 2016), while it was required to update the Plan once in five years. This clearly indicates the institutional shortcomings and lack of technical and financial capabilities of the organization to steer the water sector.

On the other hand, the BWDB has lost its planning and implementation capacity considerably by not well defining its role as a key organization in management of water resources. The long-term as well project level planning capacity of this institution reduced drastically without proper exercises. The argument was that WARPO would fill up the planning vacuum, which WARPO also failed to do. This leads one to think whether the organization is capable to plan properly and implement any large water resources project as per its mandate. In its earlier days of BWDB, a good bunch of talented engineers formed the core group of planning and design directorates of BWDB. They handled their jobs well and they could plan, design and implement the Teesta Barrage by themselves. However, that capability eroded over the years and at present, even a small project outsourced to knowledge institutes like IWM or CEGIS. The other reason of decline is that many experienced and qualified engineers have retired and the new intake got little or no training to carry out their assignments with own efforts.

From the above chapters described on the water resources development, the following points have been highlighted as conclusion of this study.

Institutional Development Perspective:

1. The water resources sector should be reorganized and revamped, the responsibility and jurisdiction of each organization involved in water resources planning, and management need redefining. The function and objectives of BWDB, WARPO, LGED, etc. need to be reviewed and redefined, so that any overlapping/ interference and encroachment over the jurisdiction are removed for the smooth administration of the agencies.
2. Due to drastic reduction of staff, BWDB has now limited scope to initiate planning for any development project; in fact, it has lost its capability of planning any project by itself and the organization is very dependent on consultants or outsourcing, which is not sustainable. To overcome the situation, the detail planning and design of water resource projects, which used to be done by BWDB professionals in the past, should be vested back to BWDB. This is more required now in the light of new concepts like Adaptive Delta Management (ADM).
3. Implementation capacity of water related agencies and institutions, especially BWDB, needs to be enhanced by providing required training to its' professional staff.
4. As mentioned in the NWMP, the implementation of the programmes listed in NWMP requires the development of the institutional capacity of the relevant agencies. The purpose is to develop each institution on sound principles, such as to separate the tasks of policy formulation, planning and regulatory functions from the implementation and operational functions, while at the same time to make these institutions accountable for financial and operational performance.
5. During 1970s' and 1980s', the engineers who worked in various planning and design directorates, remained posted to their respective offices for longer term and ultimately became the planning and design experts in their respective discipline. They were also given special financial incentives to work in the specialized areas of planning and design. At present, this practice is almost abolished and there is a continuous shuffling of engineers from one place to another. Thus, the earlier practice providing incentives, needs resumption in order to develop a set of expert professionals to deal with different projects by their own and also review the jobs carried out by the consultants.

Technical Perspectives:

6. The sources of water are getting scarce as well as quality is degrading, whereas, its demand is on increasing trend. The water bodies such as lakes and ponds should be restored and preserved, in addition rainwater

harvesting needs proper reinforcement as in the past. There is also a need for awareness building campaign for restoration of ponds and other water bodies.

7. In many cases, the railways, highways, roads, etc. constructed across the flood plains which obstructed the drainage of flood flows to the rivers. The water level differences between upstream and downstream of these infrastructures is very significant. The bridges and openings are not well designed and found to be inadequate for unhindered flood flows. Any sort of infrastructure development should keep adequate flood passage and a regulatory body needs to check the adequacy of the passage for flood flows in future.

8. Earlier, as large irrigation projects required huge fund and longer time for completion, the groundwater seemed to be a cheaper solution. So the exploitation of groundwater through shallow and deep tube wells was started by the public sector and later by the private sector too. As a result, the groundwater based irrigation system became popular and the irrigation-dependent dry season crop has become major crop in the country. However, the withdrawal of the groundwater has many limitations such as over-exploitation and drawdown of the groundwater table and damage of the ecosystems. As the groundwater is progressively going down, more sophisticated pumping sets are used. This decreases the availability of groundwater by hand pumps used for domestic purposes and the bio-diversity is also affected. Moreover, in many places, the arsenic, iron and other industrial chemical contamination of groundwater has limited its uses for domestic and agricultural purposes.

9. There has been a lack in planning of Integrated Water Resources Management (IWRM) since long. The uses of the surface water and groundwater is developing independently but not conjunctively. It is always recommended to apply conjunctive use of both surface and groundwater, but hardly practiced. It is evident that the focus of IWRM must go beyond flood control, drainage and irrigation and that the environmental consideration must be integrated into water resources management.

10. The stakeholders' participation in all layers of water management is not vigorously pursued. However, the optimal exploitation of water management could only be realized by active efforts of all the stakeholders. To achieve this, the need for reforming water institutions has become even more pronounced and it is felt that more attention must also be given to the social dimensions that promote stakeholder participation and the transfer of appropriate water management activities to the local communities. However, participatory water management was a success in projects like IPSWAM, CDSP (all 4 phases), KJDRP (during TRM), etc. and it should be replicated with more new concepts in future water sector projects. Most of the water sector projects have a strong component of participatory water management approach at present, which would be an effective way to involve local communities.

11. The construction of FCD and FCDI projects generally have negative impacts on capture fisheries. However, the culture fisheries and shrimp cultivation have increased tremendously within the flood protected areas. The remedial measures could be building fish passes as well as practicing controlled flooding of the protected lands. In this way, fish fries can enter during pre-monsoon period and thus the connectivity of the flood plains with the river systems established.

12. Any intervention in the river may affect its downstream morphology. As such, it is essential that an integrated river management plan should be prepared after thorough investigation and research. The availability of time-series satellite images has enabled the morphologists to conduct in-depth studies to gain better insight into the morphological processes of rivers in the delta. Other tools available are physical and mathematical modelling. It is better to carry out a careful research and proper plan rather than the sporadic interventions

in the rivers on assumptions, which may not work. There is a need for coordination among BWDB and other agencies for the integrated river management.

13. The rivers carry more than one billion ton of sediment annually. The upstream withdrawal of water during monsoon and post-monsoon periods has also decreased the capacity of sediment transport of the rivers to the Bay. As such, the sedimentation becomes another major problem on riverbeds, resulting in loss of conveyance capacity and navigability of many rivers. Moreover, the drainage of the agricultural floodplains are retarded due to sedimentation of rivers, resulting in water logging, which increases the soil salinity, and damage crops and alter the social structure of that particular area(specially in southwest region). Therefore, gaining profound knowledge on the sedimentation process both for inland rivers and for the sea is vital for an effective river management and more researches for this purpose.

14. The regular Operation & Maintenance (O&M) of the large infrastructure built across the country in last 60 years is required to keep them in top operating condition. The embankments erode mainly due to shifting of its riverbanks. Moreover, earthen embankments erode by wind and rainfall, human intervention as well as animal grazing. The drainage channels recurrently silt up during monsoons and floods, requiring maintenance excavation every year. Moreover, the gates of the sluices are corroded by soil salinity and other reasons. A large amount of resources is required for their maintenances every year. Because of non-availability of resources, the bank erosion cannot be prevented in time. As a result the eroded embankments have to be relocated, requiring fresh land acquisition and resources. The non-availability of resources has become a perennial problem for BWDB.

15. In 1998, a drastic restructuring of BWDB took place with a target of reducing staff from 24,000 to 8,000 based on the recommendation of the World Bank aided System Rehabilitation Project. According to many BWDB officials, this restructuring did not pay much attention to the real need of the organization. Due to retirement of experienced engineers and no or slow pace of recruitment since 1998, many field level posts remained vacant for a long time. Consequently, the regular operation and maintenance of water management systems are suffering enormously.

16. The operation and maintenance (O&M) of the water sector projects, generally speaking, is very poor. There are many factors behind it. However, as mentioned in this report (section 8.6.4), the fund provided for O&M during the last two decades was meagre in comparison to the demand for such O&M activities. In last few years, the budget given for O&M was less than 10% of requested amount. The budget for O&M needs enhancement, with proper monitoring and accountability ensured.

17. According to the National Water Policy (NWPo), WARPO is essentially to act as planning organization for water resources planning and updating of the NWMP every 5 years, but even after 12 years of its final approval, the NWMP was not updated. WARPO also has a role to coordinate, monitor all the activities related to water sector and act as "clearing house" to all water sector projects for the implementation of NWMP. However, WARPO is yet to play its due role as a clearinghouse, because of institutional capacity. In addition, the process and format of the clearinghouse needs improvement.

18. As the custodian of National Water Resources Database (NWRD), WARPO maintains a database relevant to national, regional and sub-regional planning. WARPO should develop a mechanism to update the database regularly.

19. National Water Act 2013 has provided a new role for WARPO, for which WARPO must develop a vibrant strategy, plan of actions, required manpower and a budget approved by the Government. The Act was

formulated in 2013 and WARPO was given the mandate to prepare the National Water Resources Plan (NWRP). But there seems no progress of the Plan in last three years. WARPO may be allowed to play its due role as an apex planning organization of the country in order to termination of the silo-approach in the water sector planning.

20. The physical model is an essential tool for finding sustainable as well as cost-effective solutions of water related issues. The River Research Institute (RRI) established in 1977 to assist the planning process of water resources projects, mainly through the application of physical modelling and geo-technical investigations. For the first decade of its existence, it carried out many physical models and the results were helpful in redefining the structural designs. Nevertheless, for the last few years, RRI is running below its expected level, which is certainly not a positive sign.

21. The reliable data generation and updating by the Flood Forecasting and Warning Center (FFWC) is generally good. However, the present forecasting is done for 5 days only; which needs to be extended to longer term forecasting (15 days – 30 days). Dissemination of flood forecasting and warning is done through print and electronic media, which are not easily comprehensible by the public. The community-based flood management applications need to be integrated with FFWC and forecasts are disseminated regularly to enable the members of the communities, particularly farmers and fishermen to benefit from the forecasts.

22. For the last two decades, Institute of Water Modelling (IWM) and Center for Environmental and Geographic Information Services (CEGIS) have been making invaluable contribution to water sector projects and these two Trust organizations are maintaining a vast quantity of water related national databases. Over the years, both the organizations have developed huge reputation at home and abroad. These institutions should be supported to conduct and develop innovative knowledge products for finding solutions for water sector issues in future.

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BASELINE STUDY: 02

River System Management

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Executive Summary: Study 02

Major rivers, including the Ganges, Brahmaputra-Jamuna, Padma and Meghna and their numerous tributaries and distributaries make Bangladesh a land of rivers. These rivers which originate in the young mountains across the national borders of Bangladesh, are very dynamic in nature, as the land mass is composed of recent deltaic deposits. There is no denying of the fact that rivers are the most eminent feature influencing the overall socio-economic condition of the over populated country, Bangladesh. In the rural areas, people are mainly dependent on the agricultural land resources for living and agricultural sector is dependent on river system for irrigation and drainage aspects. A large number of rural people are dependent on rivers for their living as fisherman, boatman and by other business activities. Moreover, the river system also plays an important role in the urban areas as the water supply and the industrial sector is heavily dependent on the river resources. Navigation is a very important aspect of economic activities of the country.

The rivers also cause immense suffering to people of Bangladesh. River bank erosion is a serious hazard that directly or indirectly causes the suffering of about one million people annually (Elahi, 1990). A large number of people living in both rural and urban areas become the victims of flooding annually. These two hazards – flooding and river erosion – are major contributors to the process of impoverisation of people in this country.

Thus, river management is an inevitable need for utilizing the river resources for the development of this country. In most of the countries the large rivers are well trained and the nations are benefiting through using river resources. Many developed cities, industrial areas around the world have been established along the banks of the large rivers for using the resources and benefits of these rivers. In Bangladesh, particularly the rural people, along the river banks, are living in the lower poverty level. Understanding on the river system of this country is necessary to ensure proper river management. In this regard, the base condition of the regional river system has been analyzed in this report.

The development and characteristics of any river system is closely related to the geological and physiographical setting of different regions. Thus the geological and physiographical setting of the country has been discussed in this report. Analysis of geological setting depicts that the Bengal Basin has been filled by sediments derived from erosion of the highland boundaries on all three landward sides. However, the main source of the sediment has been the Himalayas due to their alpine nature. Since the Pleistocene, the Ganges has, together with the Brahmaputra, delivered enormous quantities of sediment to the Bengal Basin. These sediments have formed the world's largest river delta with an area of about 100,000 km^2. About 90% of the land area of Bangladesh is formed by recently deposited, alluvial and deltaic sediments. In physiographical setting it is shown that Bangladesh comprises 30 agro-ecological regions which have developed based on physiography, soil properties, soil salinity, depth and duration of flooding which are relevant for land use and for the assessment of agricultural potential.

Digital Elevation Model (DEM) based on the surveys of 1950s has been used to analyze the topographical setting. The dominating slopes have been identified and the characteristics of the rivers have been described in this connection. The major features of Bangladesh surface is the high level of the Barind Tract and the Madhupur Tract. It is observed from the DEM that the dominating topographic slopes are directed towards southeast in the western part and southwest in the eastern part of Bangladesh. In discussing the hydrological setting, the gross area of each hydrological region was determined (Figure 2.8).

The evolution of the overall river system of Bangladesh has been discussed to portray the distinctiveness of the river system of this country. The river system of this delta has evolved through various changes and these changes are interlinked with each other. The geo-morphological characteristics, base condition and key problems of the major rivers (the Jamuna, the Padma, the Ganges and the Meghna) have been described as they influence the overall river system significantly. For instance about 200 years ago, a significant amount of the Brahmaputra flows diverted to the present Jamuna River to meet the Ganges due to the avulsion of the Teesta River and other tectonic activities. By the early 20th century, most of the Brahmaputra flow was diverted to the Jamuna River and most of the Padma flow was diverted to the Meghna River turning its old course, along the Arial Khan River, into its right bank distributary. This avulsion has greatly influenced significant changes in North-East, North-West and South-East regions.

The characteristics of the rivers of Bangladesh vary significantly within different regions due to diversification in physical setting of different regions. Thus regional analysis has been conducted in terms of geographical and topographical setting, historical development and key problems or concerns of particular regions. Additionally, description and specific problems of some important rivers have been provided region wise.

In North-West Region, the Barind Tract and the Atrai basin, a part of the Chalan Beel have been identified as the controlling features for land and river development. The avulsion of the Teesta River is considered as one of the important factors for river development in this region. Avulsion and westward shifting of the Brahmmaputra River and construction of Teesta Barrage have caused other significant changes in this region. Erosion, navigation during dry season, high extraction of groundwater, flood and water scarcity for irrigation are the major problems of this region.

In North-Central Region high level of the Madhupur Tract is the controlling feature and has made the whole region southwest aligned extending. The region being gradually lower towards northwest-southeast direction, most of the rivers take off from the Brahmaputra- Jamuna and the Old Brahmaputra and some drain into the Padma River and others into the Meghna River. Enormous sediment supply from upstream through Jamuna and its avulsion attributed to the off-take sedimentation of major rivers of this region. Maintaining navigation facilities is a major problem for this region as many rivers have become morphologically inactive. Discharged effluence and waste materials from industries have caused deterioration of water quality significantly.

A tectonically active basin is situated at the central part of North-East Region which is subsiding. This basin is draining an area which generates the highest rainfall in the world through an outlet in the south. Net subsidence of this basin due to lack of sediment in this region is one of the main reasons for the avulsion of the rivers. Subsidence can also cause avulsion of rivers, changes in their planform pattern and increase or decrease of sinuosity. This increased subsidence rate is mainly caused by the sediment starvation due to the avulsion of the Brahmaputra River. Moreover, the northern part of the region being most depressed, the rivers showed a tendency of shifting towards the north. Proper sediment management is very significant for this region to compensate the subsidence and other effects of climate change and at the same time to maintain the ecosystem.

More than half of the South-West and South-Central regions are influenced by tide and salinity intrusion is a common feature for several kilometers inland from the Bay of Bengal. This is a complex region of inter-linked ecosystems in the delta of the Ganges-Brahmaputra Rivers. Delta progradation or delta building process is the most eminent feature of this region which is influenced by tectonic and seismic activities.This active delta building process has impact on accelerating the dynamics of rivers and Meghna Estuary of this region. This region is severely vulnerable in terms of climate change and sea level rise. Lack of fresh water, salinity, groundwater arsenic and subsidence of polders are the major problems of this region.

The rivers in South-East Region are less dynamic compared to the other regions of Bangladesh. So their planform has not changed significantly during the course of time. But the drainage condition of this region has deteriorated with time, mainly due to neo-tectonics and delta building process. Tectonical uplift and subsequent subsidence along the subsurface Anticlines and Synclines together with delta progradation at the south margin of this region result in flooding and drainage congestion. Navigation problems are available in the upstream part of some rivers which is impeding commercial activities.

The topography of the Eastern Hill Region being different from the rest of the country, the rivers of this region are different as well. These rivers did not change the same way as did rivers of the other regions. Rivers in the hilly region mainly follow the terrain of the hills. Most of the rivers of this region are flashy in nature and bank erosion occurs along the banks. Sedimentation due to deforestation and hilly cultivation practices causes navigation problem.

Different national plans named IECO Master Plan by East Pakistan Water and Power Development Authority (EPWAPDA) 1964, Bangladesh Land and Water Resources Sector Study (IBRD), National Water Plan (NWP) and National Water Management Plan (NWMP) have been reviewed. Different policies like National Environmental Policy (1992), National Water Policy (NWPo) (1999) and Coastal Zone Policy (2005) have been reviewed in this report. Strategy documents like Bangladesh Water and Flood Management Strategy (1995), Coastal Development Strategy (2006), National Climate Change Strategy and Action Plan (2009), Poverty Reduction Strategy Paper (2009) and Water Act (2013) have been reviewed. Different drivers have been identified region wise as their effect varies significantly in different regions.

In North-West and North-Central, human intervention, Teesta and Brahmmaputra avulsion were identified to be the main drivers. In North-East, tectonic subsidence and Brahmmaputra avulsion were the main drivers. On the other hand, tectonic uplifting was the main driver in South-East. Deltaic subsidence, human intervention, Brahmmaputra avulsion and Ganges shifting have been identified to be the major drivers of the South-West Region. Moreover, effects of climate change have been discussed as future driver. As the rivers of this country are very dynamic and carry huge amount of sediment, climate change is expected to have eminent impact on the river system through both exogenous and endogenous factors. Exogenous factors include sea level rise and increased precipitation which will have long term effect on the development of this delta as well as the river system. Endogenous factors include changes of sediment input which is sensitive to human interventions and natural hazards such as earthquakes may have impacts on decade-scale process.

The long term challenges in preparing a sustainable and adaptable long term plan have been identified. Dealing with different issues like developing a vision, optimization of resources, maintaining connectivity of the river system, climate change and upstream intervention both within country and also beyond the international border have been considered to be the main challenges in national level. Regional challenges have been also identified more specifically. In North-West Region controlling groundwater mining will be a challenging issue especially in the Barind Tract. Controlling the upstream intervention at international and local levels will be another challenge for this region. For North-Central Region, it would be challenging to maintain regulated flow which can facilitate in improving water quality and at the same time will not make the banks of the rivers erosion prone. On the other hand maintaining proper sediment balance will be very challenging in North-East Region as different sectors are related to it. In South-West Region, maintaining fresh water flow and sediment management in polder areas have been identified to be the major challenges. It has been identified that the main challenge will be to deal with drainage congestion in South-East Region.

There are diffent interlinking aspects, like Regional Cooperation, Agriculture and Food Security, Fisheries, Ecological Settings and Biodiversity, Environmental Pollution, Land Resource and Population Management, Climate Change, Disaster Management, Coastal Development, Socio-economic aspects and Water Resources, which are very much related with the River Management issues. The knowledge gaps in developing of long term plans for river management issues have been identified. Training of the large rivers ensuring optimum utilization of river resources, river responses to the climate change, making balance between economic development and sustainability of the delta in times of climate change, lack of information and uncertainty regarding upstream intervention and lack of sediment data have been observed to be the knowledge gaps in river management sector.

Moreover, some comments have been provided upon reviewing the Sixth Five Year Plan (SFYP) in terms of river management. In SFYP river dredging, protection of river erosion, land reclamation, regional and international cooperation for management of trans-boundary rivers have been set as specific objectives for the water sector. Although land reclamation is viewed as a priority issue, as Bangladesh is a land hungry country and is set as an objective of water sector, there is no special reference for land reclamation through river management. Additionally some projects have been suggested for different regions which can be incorporated in the Seventh Five Year Plan. The projects include preparing master plan for managing the main rivers of Bangladesh, undertaking pilot project for land reclamation in the Jamuna River and pilot project for allowing regulated sediment intrusion in polder areas and conducting a study to understand the future development of the Sylhet Basin.

1. Introduction

1.1. Background

The Ganges, Brahmaputra and Meghna [GBM] River System built the Bengal Delta, which is one of the largest of its kind in the world. Major rivers, including the Ganges, the Brahmaputra-Jamuna, the Padma and the Meghna and their numerous tributaries and distributaries made Bangladesh a land of rivers. The catchment area of these rivers is about 1.65 million km^2 of which only 7.5% lies within the borders of Bangladesh (Sarker M. H., 2003). This catchment generates 120 million ha-m of runoff, annually, of which only 10% is generated within Bangladesh. In addition to the vast quantity of water, these rivers carry about 1.1 billion tons of sediment every year (EGIS, 2000); (Sarker M. H., 2003). These rivers are very dynamic in nature, as the land mass is composed of recent deltaic deposits and the major rivers originate in young mountains across the country's borders, such as the Himalayas, the Meghalaya and the Tripura Hills, in India, China, Nepal and Bhutan. These young mountains yield huge quantities of sediment due to their active tectonic movements, wind and rain activities in the regions, and snow melting.

Rivers are the most eminent feature influencing the overall socio-economic condition of the over populated country. High population density can be observed along the banks of the rivers (**Figure 1.1**). Most of the people of Bangladesh still live in the rural areas (**Figure 1.2**) and are mainly dependent on the agricultural land resources for their livelihood. These land resources are closely related to the flow regimes of both large and small rivers. Additionally, a large number of rural people are dependent on rivers for earning a living as fisherman, boatman and by other business activities. Moreover, the river system also plays an important role in urban areas, as the water supply and industrialization sector is heavily dependent on the river resources. Navigation too is a vital economic sector of the country.

The rivers also cause immense suffering to the people of this country. River bank erosion is a serious hazard that directly or indirectly causes suffering among approximately one million people, annually (Elahi, 1990). A large number of people living in both rural and urban areas become the victims of flooding every year. These two hazards – flooding and river erosion – are major contributors to the process of impoverisation of people of Bangladesh. Moreover, unplanned industrialization along the banks causes deterioration of water quality and ecosystem affecting the whole environment.

Bangladesh is blessed with huge water resources with the crisscrossed river system all over its land. But Bangladesh has been unable to exploit the river resources. In most of the countries, the large rivers are well trained and the nations are benefiting by using river resources. Many developed cities and industrial areas around the world have been established along the banks of the large rivers for using the resources and benefits of these rivers. In Bangladesh too, some of the major cities (Dhaka, Chittagong, Khulna, Barisal, Rajshahi and Sylhet) are located on the river banks. However, it is also true that people who are at the lower level of poverty in Bangladesh, particularly in the rural areas, live along the river banks (Figure 1.2). River related hazards have restricted their economic and social development. In addition to that the rivers, being very dynamic and their bankline movements very rapid, they restrict the development of cities and commercial centers along their banks, and thereby, jeopardize the country's economic development. Due to poor economy, lack of proper understanding on the river system, and non-availability of cheaper construction materials as well as lack of proper attention of policy makers, a very potential arena has remained unexplored in this country. Thus, river management is an inevitable need for utilizing the river resources for the development of this country. The whole Bangladesh is considered as the study area for this study.

Population Density Map of Bangladesh, 2011

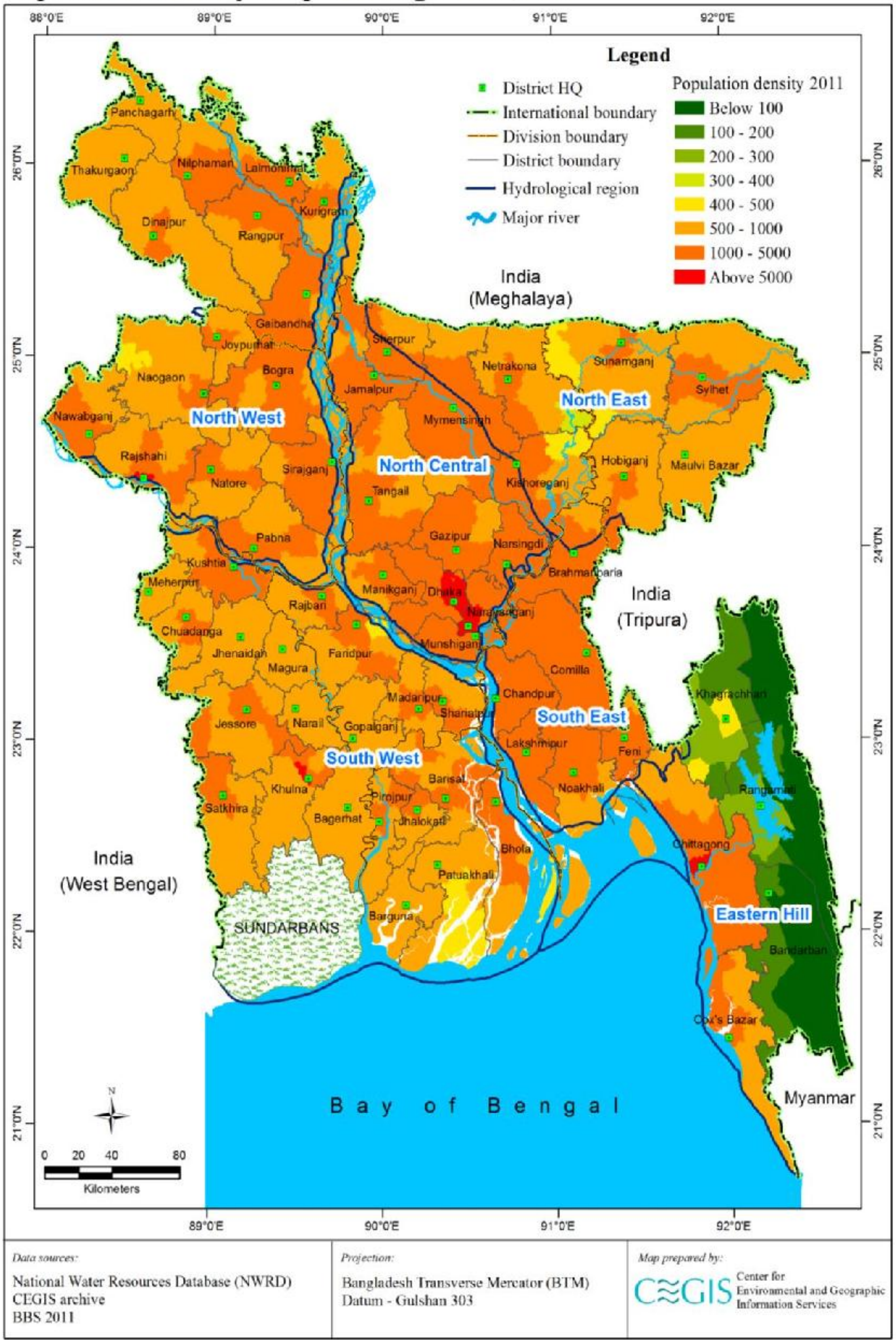

Figure 1.1: Population density of Bangladesh (BBS, 2011)

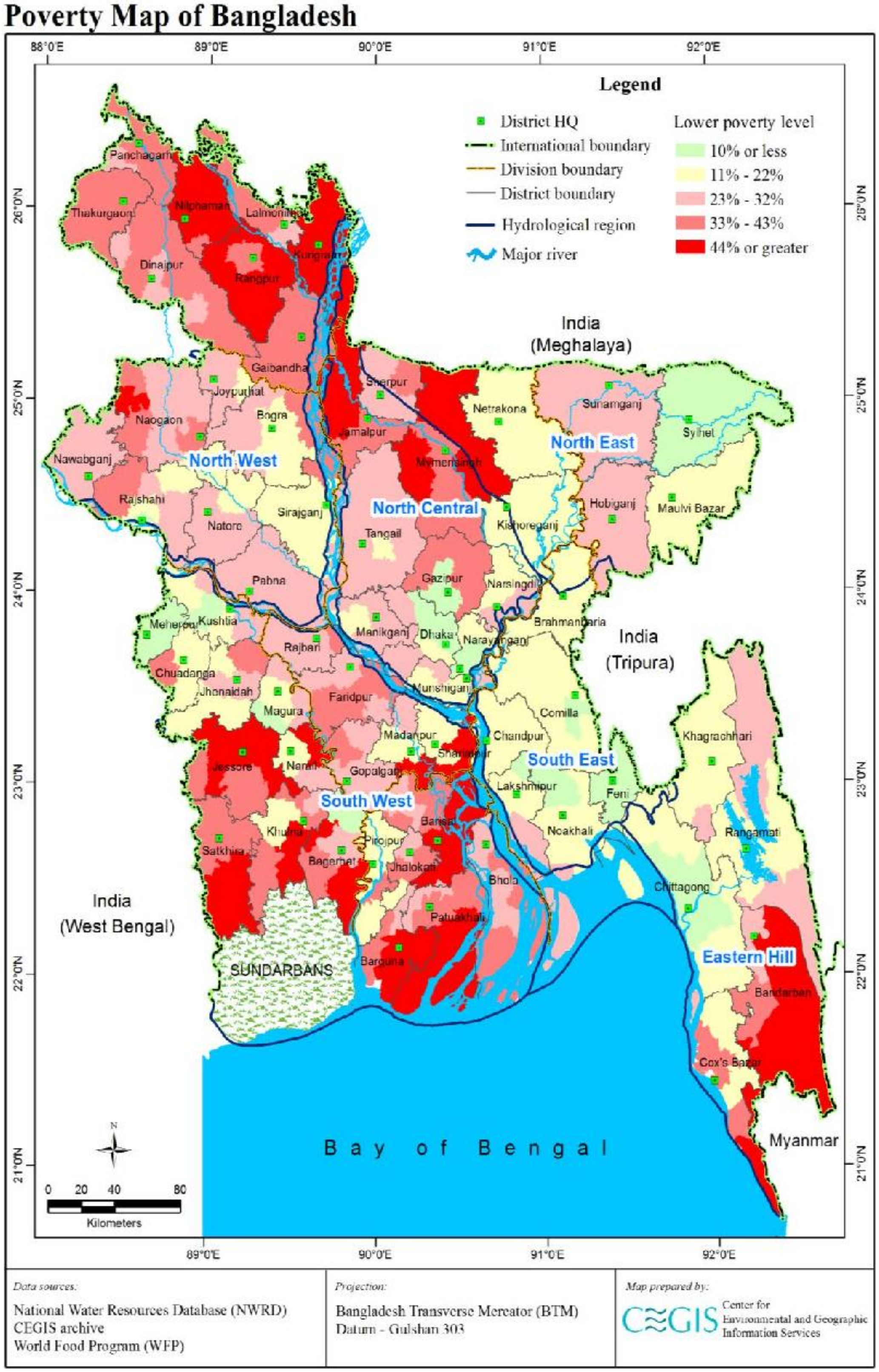

Figure 1.2: Poverty level of Bangladesh (BBS, 2005)

1.2. Objectives

The objectives of the River System Management study are:

- To conceive the knowledge available on the prevailing physical processes, probable future changes in the light of climate changes and human interventions.
- To evaluate the existing problems and future developments, (government) plans in view of the long-term (socio-economic and climate) changes.
- To facilitate the identification of challenges and opportunities for the BDP2100 (also Priority ranking). Translate towards the building blocks for Delta Vision and development, as well as 7^{th} Five Year Plan.
- To recognize strategy and measures (No-regret).
- To create a common knowledge base
- To identify knowledge gap and research needs
- To identify exemplary projects for implementation.

1.3. Structure of the Report

In this report there are six chapters. The first chapter is introduction of this study. In the second chapter, the physical setting (geological setting, topographical setting, physiographical setting and hydrological setting) of Bangladesh has been described in details. The geo-morphological characteristics of the major and the regional rivers are described in the third and the forth chapters respectively. The previous studies, plans, policies and strategies are delineated in the fifth chapter. The drivers, long term challenges, knowledge gaps are presented in sixth chapter.

2. Physical Setting of Bangladesh

2.1. Geological Setting

The geology of the Indo-Australian Plate on which Bangladesh lies, is predominantly the result of plate tectonics. The Indo-Australian Plate was separated from the Euro-Asian Plate by the Tethys Sea prior to the Palaeocene (65 million years ago). During the Eocene (54 to 38 million years Before the Present) the Indo-Australian Plate collided with the southern edge of the Euro-Asian Plate (Rashid, 1991). Since then, the Indo-Australian Plate has advancedabout 2,000 km northwards, passing beneath the Euro-Asian Plate, uplifting it and crumpling its southern edge to form the Tibetan Plateau and the Himalayas, respectively (Rashid, 1991).

The Indian Plate is subducted along the line of the Himalayas, but at the eastern boundary the plates rub past each other along transform faults (**Figure 2.1**). During the Oligocene Epoch (38 to 26 million years Before the Present), the north-eastern part of the Indian Plate in the vicinity of the junction of the sub-duction zone and the eastern transform fault, fractured and sank below the sea-level to form the Bengal Basin. The northern part of this basin was then gradually filled up by sediments carried by surface waters draining into it (Figure 2.1).

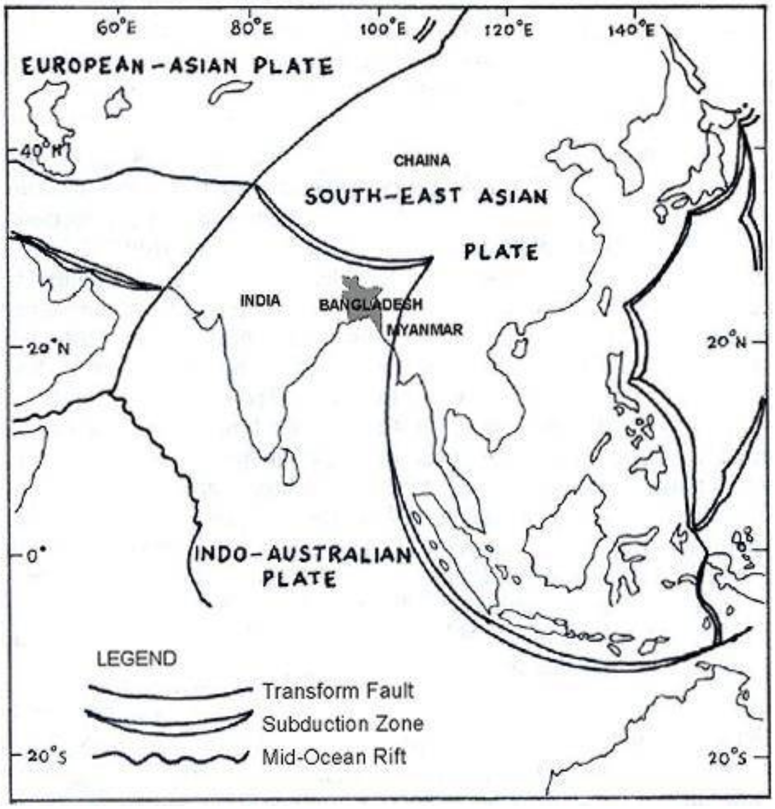

Figure 2.1: Tectonic Map of the Indo-Australian and Euro-Asian Plates (Rashid, 1991)

The Pre-Cambrian rock beneath the northern part of the Bengal Basin is tilted from the northwest to the southeast along a hinge line that developed during the Eocene. The hinge line divides the basin into two zones (Alam, 1990). The sedimentary fill in the northwest is relatively thin, with a minimum thickness of 350 m, as the basement rock is close to the land surface (Khan, 1991). In contrast, the sediment fill in the southeast of the hinge line is extremely thick, reaching a maximum of about 18 km at Barisal.

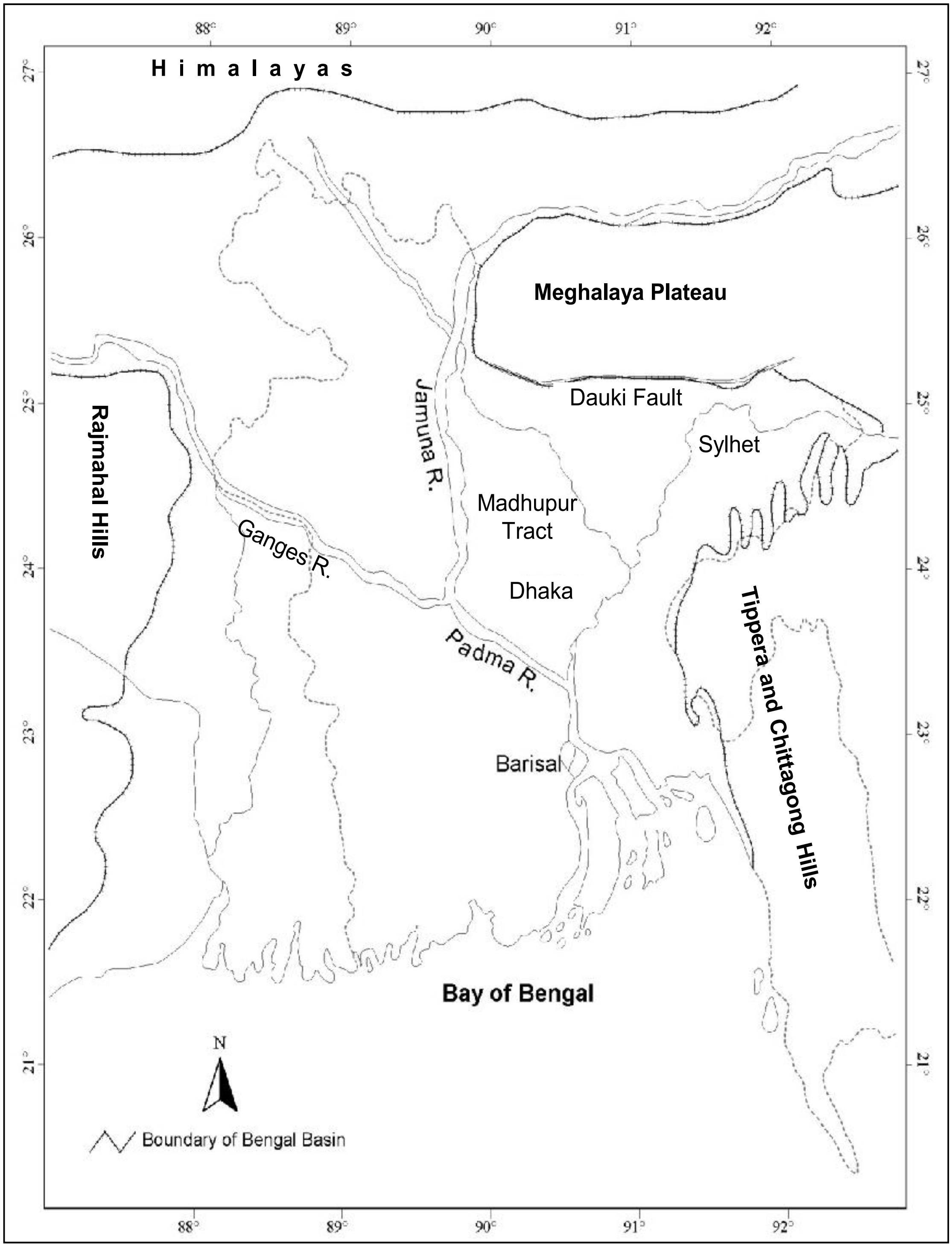

Figure 2.2: Boundaries of the Bengal Basin (Rashid, 1991)

The Bengal Basin is bounded by the Rajmahal Hills to the west, the Himalayas to the north and the Tippera Hills and Chittagong Hills to the east (Figure 2.2). Within the basin, the Shillong Hills occupy an area close to the Bangladesh-Indian border in the northeast corner. The Shillong Hills are formed by the uplifted Shillong Block, which is separated from the subsiding Sylhet Basin to the south by the Dauki Fault (**Figure 2.2**).

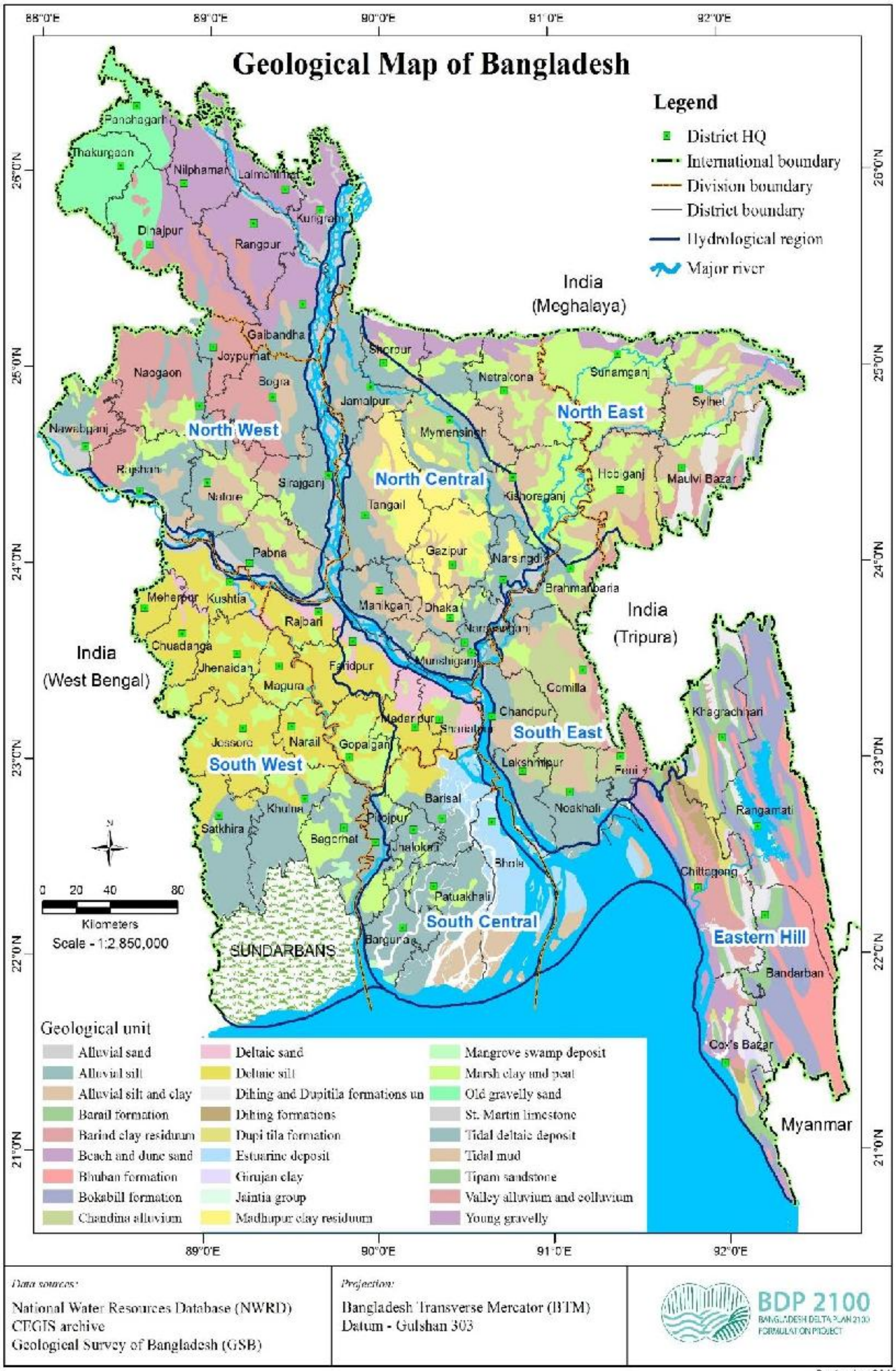

Figure 2.3: Geological setting of Bangladesh (NWRD, 1990)

The Bengal Basin has been filled by sediments derived from erosion of the highland boundaries on all three landward sides. However, the main source of the sediment has been the Himalayas due to their alpine nature, which features very high elevations, steep slopes and young rocks that are vulnerable to physical weathering and erosion. For millions of years, sediments eroded from the Himalayas have been carried to the basin by the rivers Ganges and Brahmaputra, the two very large rivers which rise in the Himalayas. The Ganges has not always drained from the Himalayas to the Bengal Basin however, as it only broke through the eastern margin of the Rajmahal Hills to enter the basin during the Pleistocene (Bhuiya, 1993). Since the Pleistocene, the Ganges has, together with the Brahmaputra, delivered enormous quantities of sediment to the Bengal Basin. These sediments have formed the world's largest river delta with an area of about 100,000 km^2 and a sub-aquatic fan extending 3,000 km south into the Bay of Bengal (Goodbred Jr., Kuehl, Stecler, & Sarker, 2003).

About 90% of the land area of Bangladesh has been formed by recently deposited alluvial and deltaic sediments. The surficial topography of the fan within Bangladesh is very subdued. The highest elevation is only 90 m above sea-level (asl) in the northwest corner of the country, with 75% of Bangladesh lying below 29 m asl and 50% below 12.5 m (Halcrow, DHI, EPC, & Sangshad, 1993). The remaining 10% of Bangladesh is formed by raised blocks of older Pleistocene sediments making up the Barind Tract, the Madhupur Tract and the Lalmai Hills (Khan, 1991). These sediments were formed through floodplain deposition by the Ganges and the Brahmaputra rivers, before being uplifted tectonically (Morgan & McIntire, 1959); (Monsur, 1995). The sediments forming these blocks have been intensely weathered and extensively oxidized, giving the uplifted blocks relatively rugged relief that contrasts with the low relief of the deltaic plains and contemporary floodplains formed in the more recent sediments.

2.2. Topographical Setting

Digital Elevation Model (DEM) of 1950s, generated from the agriculture map, has been used to understand the overall geomorphology of Bangladesh. In addition, region-wise description of the land morphology is described in the subsequent sections. The resolution of the DEM is coarse (300 m x300m) and it does not cover the river depths. However, the levees with high elevation formed along both sides of the river courses can be recognized in the DEM. Moreover, the DEM agrees well with the physiographical units of Bangladesh.

The major features of Bangladesh surface is the high level of the Barind Tract and the Madhupur Tract. It is observed from the DEM that the dominating topographic slopes are directed towards southeast in the western part and southwest in the eastern part of Bangladesh. The valley slope, i.e. the lowest region of Bangladesh, stretches along the Madaripur-Gopalganj Beel Route, the Upper Meghna River and the Sylhet Basin, which has land elevation below 5 mPWD. To diagnose the terrain characteristics of Bangladesh, a number of sectional profiles have been extracted from the DEM as shown in **Figure 2.4**. Out of these, Sections A, B, C, D, and E are east-west aligned and Sections M, N and O are north-south aligned. Region-wise detailed description has been made in the subsequent sections.

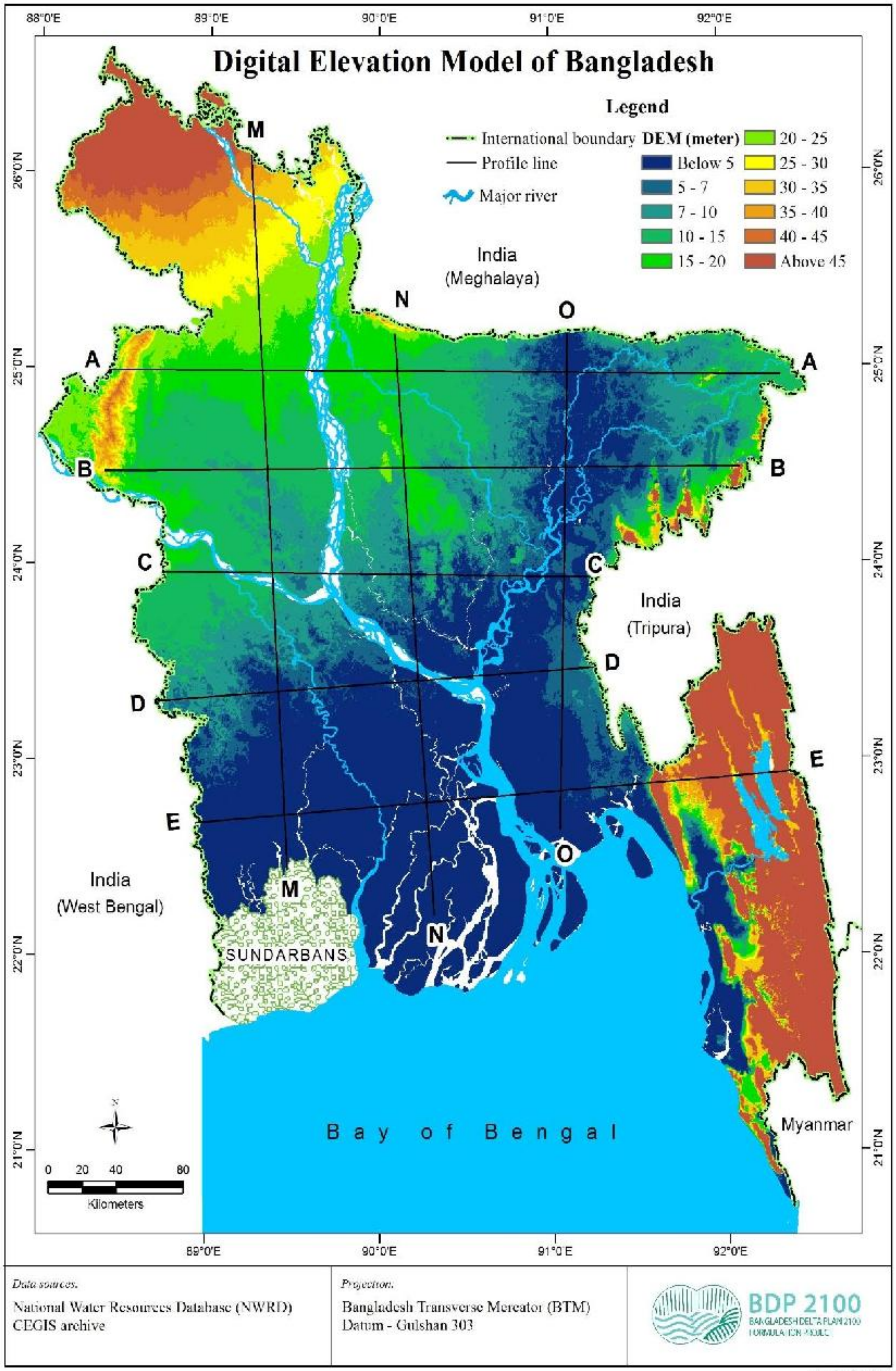

Figure 2.4: Digital Elevation Model of Bangladesh (NWRD 1964)

Three surface profiles of Sections M, N and O are shown in **Figure 2.4** and **Figure 2.5**. North-south directed surface profile of Section"M" shows clear land elevation from more than 40 mPWD of the Teesta Meander Floodplain to about 2 mPWD of the tidal plain. Sequential elevations follow the level and slope of the Barind Tract, the Ganges Floodplain and finally, the tidal plain with almost no gradient. The land slope from the Teesta Meander Floodplain to the Active Ganges Floodplain is about 18 cm/km and the slope of the Ganges Floodplain is about 8 cm/km. The surface of Section "N" also clearly indicates the higher elevations of the Madhupur Tract and lower elevation of the Arial Beel. The land elevation from the northern and the eastern piedmont plain to the Ganges Tidal Plain varies from 20 mPWd to 2 mPWD. Finally, the Section "O" indicates the northward sloping levels of the Sylhet Basin and the higher elevated estuarine floodplain, which is also a part of Indo-Burman Arc folds. This part could be one of few last folds; those could be leveled up by the floodplain or tidal sedimentation. Most of the Section "O" surface is below 5 mPWD, except the Titas Terrace.

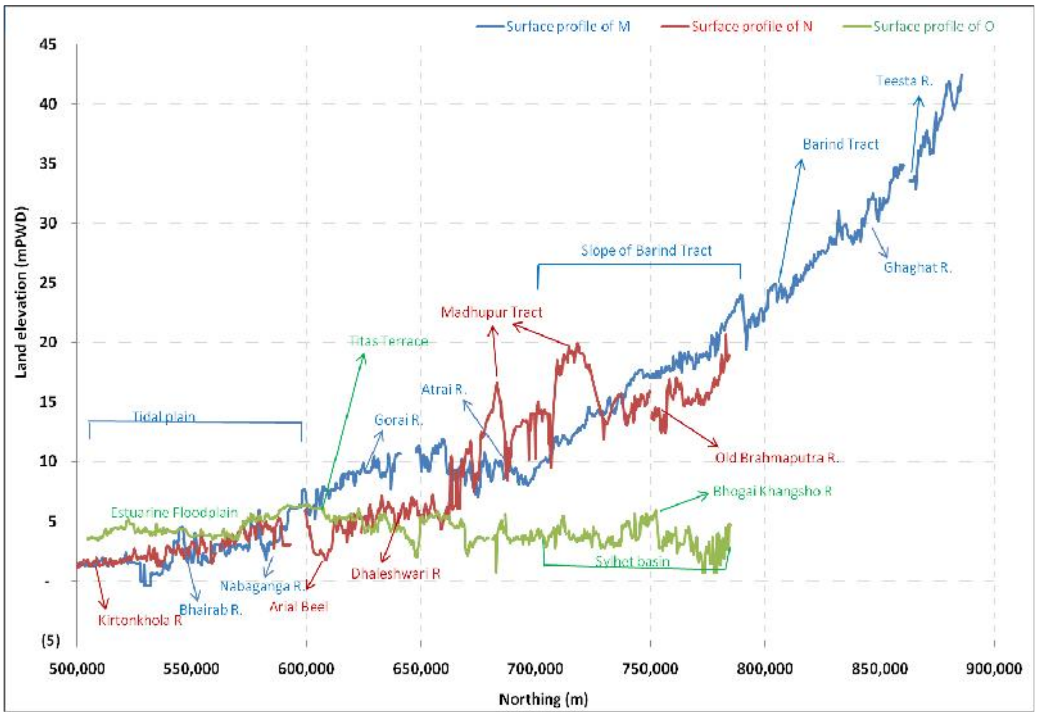

Figure 2.5: Elevations of cross profiles of north south directed three sections

East-West directed surface profiles of Sections A, B, C, D and E, as in Figure 2.4 and **Figure 2.6**, show that the elevation difference in the western part of Bangladesh is about 16 m, whereas there is almost no difference in the eastern part, except Meghna Estuarine Floodplain in the South-East region. Teesta Meander Floodplain is bounded by the Level Barind Tract at the east and west sides in the surface profile of Section A. The Left bank of the Jamuna River is one meter elevated than that of in the right bank. After extending the Old Brahmaputra Floodplain, the Sylhet Basin is stretched about 50 km leveling from 8 mPWD to 2 mPWD. The slope of the Old Brahmaputra Floodplain is about 12 cm/km as found from the surface profile of A. The Sylhet city is about 20 m higher than the floor of the Sylhet Basin.

East-west extended surface profile of Section B shows that there are two natural controls of geo-morphological development- High Barind Tract and the Madhupur Tract. In between these two, the level of the Atrai Basin is found to be below 9 mPWD. The Atrai River flows along the deepest part of the basin. The level of left bank of the Jamuna is found to be higher than that of the right bank. In between the Madhupur Tract and the Old Brahmaputra River, the Khairo Riveris flowing at the lowest level at easting 542 km.

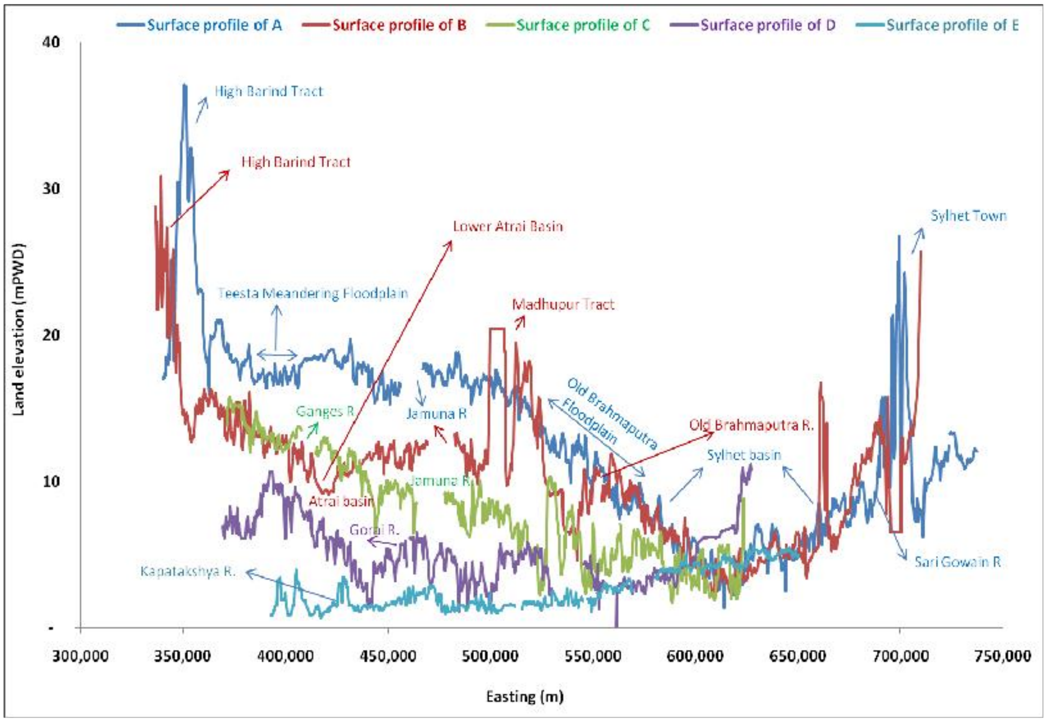

Figure 2.6: Elevations of cross profiles of east west directed five sections

Surface profile of Section C shows a gentle land slope from the beginning till it meets the Lower Meghna River at 587 km. The elevated part starting from 525 km to 544 km is almost the last part of the Madhupur Tract. Surface profile of section D shows a very mild slope upto 530 km easting where the Padma River begins. In this part, three highly elevated areas are visible. Those are developed by the rivers Bhairab, Gorai and Arial Khan. Finally, the surface profile of Section E shows a different character with a negative slope from the eastern boundary of Bangladesh. From the starting to easting 550 km, there is almost no slope as it is a complete tidal plain, where tide plays a key role in sediment distribution.

2.3. Physiographical Setting of Bangladesh

As per the Land Resources Appraisal of Bangladesh for Agricultural Development, Bangladesh comprises 30 agro-ecological regions which are shown in **Figure 2.7**. These regions have been demarceted based on physiography, soil properties, soil salinity, depth and duration of flooding which are relevant for land use and for the assessment of agricultural potential. The main features of some major agro-ecological regions have been described below.

Active Teesta Floodplain

This region has complex patterns of low, generally smooth, ridges, inter-ridge depressions, river channels and cutoff channels. The land areas are subject to change in outline and relief each year due to shifting river channels and deposition of new alluvium. In this floodplain irregular patterns of gray, stratified sands and silts predominate with some developed gray, silty soils near the boundaries with the Teesta Meander Floodplain. Sandy and silty deposits are roughly equal on this floodplain.

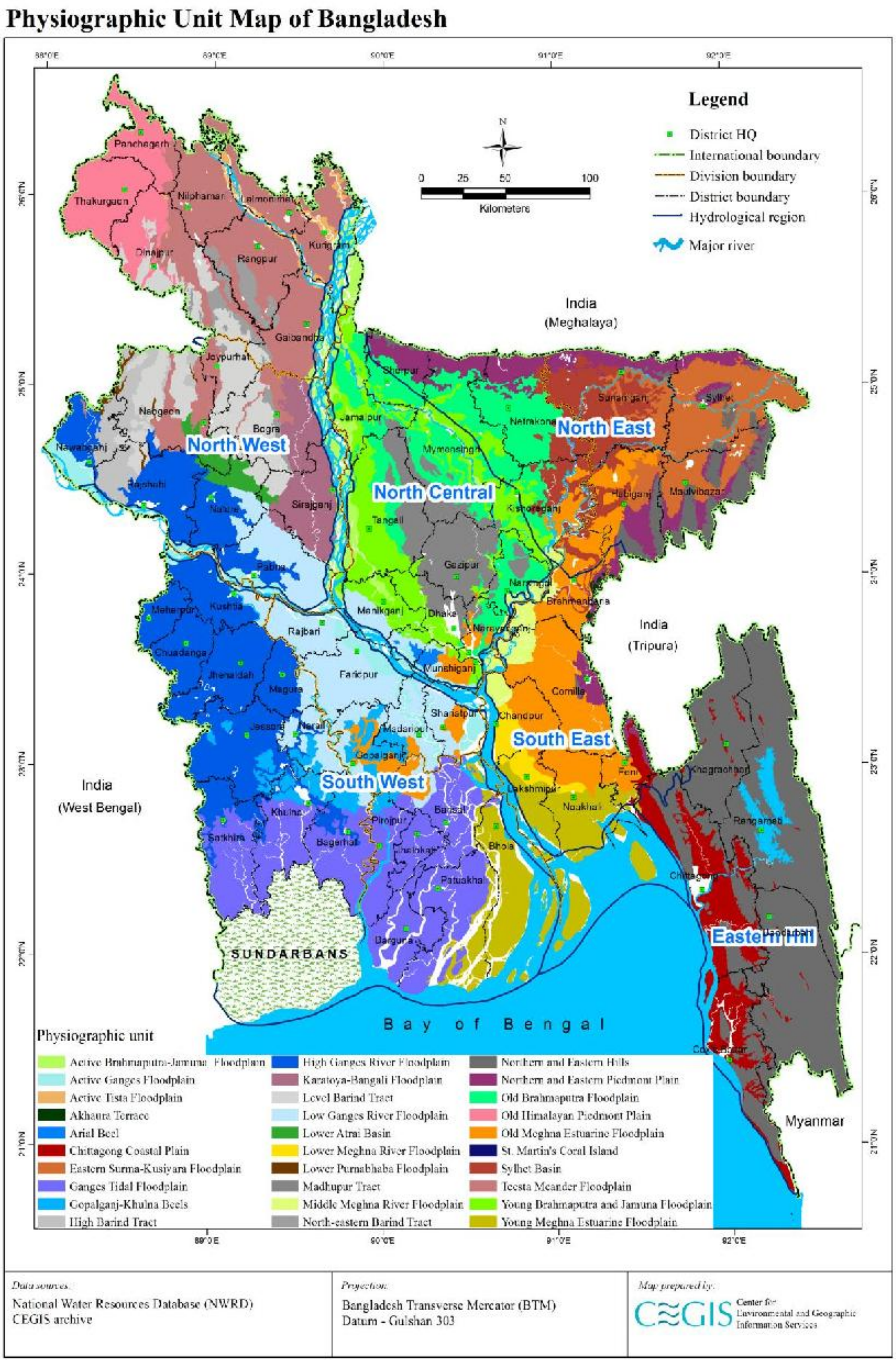

Figure 2.7: Agro-ecological regions of Bangladesh

Source: Land Resources Appraisal of Bangladesh for agricultural development

Teesta Meander Floodplain

Most areas in this region have broad floodplain ridges and almost level basins. Locally, relief is irregular alongside rivers, with narrower ridges, depressions and in filled channels. In general, ridges stand higher and more extensive in the north- west than in the south and east. Many raised cultivation platform exist in the southern part.

There is an overall pattern of olive-brown, rapidly permeable loamy soils on the upper parts of high floodplain ridges, and gray or dark gray, slowly permeable, heavy silt loam or silty clay loam soils on lower land. Clay soils occupy small areas in basin centers but they are at the rear in other parts. Silty Teesta floodplain soils have a very high moisture- holding capacity. Shallower loamy ridge soils over lying sand become droughty in the dry season.

Active Brahmaputra-Jamuna Floodplain

The region has an irregular relief of broad narrow ridges and depressions, interrupted by cut-off channels and active channels. Both the outline and relief of char formation are liable to change each flood season by shifting channels and to deposition of irregular thicknesses of new alluvium. Local differences in elevation are mainly 2-5 meters.

Complex mixtures of sandy and silty alluvium occupy most char land but there are some developed gray silty soils on older areas of alluvium, especially along the eastern side. The proportions of sandy and silty alluvium vary from place to place and from year to year. Overall silty deposit are more extensive than sandy deposits especially in the south and on relatively older land. However large areas of sand may be deposited in high flood year especially in the north.

Active Ganges Floodplain

Char areas have an irregular relief of broad and narrow ridges and depressions, interrupted by cut-off channels. Both the outline and relief of char formations are liable to change in each flood season due to bank erosion by shifting channels and deposition of irregular thicknesses of new alluvium. Local differences in elevation are mainly 2-5 m, but become less in the south near the Meghna estuary.

The ridges have complex mixtures of calcareous sandy silty and clay alluvium, with some shallowly developed loamy soils and depressions have dark gray clays on older alluvial areas. The proportions of sandy, silty and clay alluvium vary from place to place and from year to year. Downstream from the Ganges- Jamuna confluences, the proportion of Ganges and Jamuna sediments also vary from year to year. Silty Ganges material is browner and calcareous. Silty Jamuna alluvium is gray or grayish brown and noncalcareous, overall silty sediments are more extensive than sandy one especially in upper and lower sub regions. In addition to lime, Ganges alluvium is also rich in weatheable minerals, and a proportion of its clay fraction is swelling clay.

Eastern Surma-Kushiyara Floodplain

This floodplain has mainly smooth broad, ridges and basins with 3-6 m local differences in elevation. Along the lower Kushiyara river, there is a broad belt of irregular relief, with narrow, liner ridges and inter- ridge depressions. Minor areas of small, low, hillocks occur locally in the east, too small to map separately. Gray, heavy, silty clay loam and clays predominates in this region. Small areas of loamy soils occur alongside rivers, together with mixed sandy and silty alluvium. Peat occupies some wet basin centers. Permeability is slow in most soils. Moisture-holding capacity is inherently moderate but is reduced by puddling of the surface layer. Except in wet basin centers, top soils quickly become hard and dry after the end of the rainy season and basin soils crack widely.

Ganges Tidal Floodplain

The greater part of this region has smooth relief. River banks generally stand about a meter or less above the level of adjoining basins. The region is characterized by a close network of interconnected, tidal rivers and creaks. In the west, these channels are saline throughout the year, although less saline in the rainy season than in the dry season. In the east, channels carry fresh water in the rainy season, and salinity only affects channels in dry season, mainly in the second half of the dry season.

There is a general pattern of gray, slightly calcareous, loamy soils on river banks and gray or dark gray, non calcareous, heavy silty clays in the extensive basins. Soils become slightly saline to strongly saline at the surface during the dry season, and soils in some portion are subject to tidal flooding with brackish or saline water throughout the year

Old Brahmaputra Floodplain

Most areas of this floodplain have broad ridges and basins. Relief is locally irregular, especially near old and present river channels. The difference in elevation between ridge tops and basin centers usually is 2-5 meters, but it exceeds 5 meters near the boundary with the Sylhet Basin.

Dark gray floodplain soils generally predominate. However ridges have brown flood-plain soils, gray valley soils, varying proportion of gray valley plain soils .Ridge soils are mainly silt loam and silty clay loam. Clays predominate in basins.

The higher ridge soils are rapidly permeable. Lower ridge soils used are slowly permeable, so are basin clays. Moisture holding capacity is high in deep silt loam on ridges, but is moderate or low in more sandy or shallow ridge soils and in basin clays.

Sylhet Basin

The region is mostly smooth it has broad basins with narrow rims of higher land along rivers. Relief is locally irregular near to rivers. The difference in elevation between river banks and adjoining basin centers is 3-6 m or more.

There are two main kinds of soils in this region:

- Gray silty clay loams and clay with developed profiles which occur on the relatively higher land which dries out seasonally
- Gray clays with raw alluvium at a shallow depth which occupy basins which stay wet throughout the year

Young Meghna Estuarine Floodplain

The region is almost level with very low ridges and broad depressions. There are few or no creeks, except on tidally flooded margins. Shifting channels constantly erode land and deposit new char formations.

The main soils are gray to olive, deep, silt loams and silty clay loams which are stratified either throughout or at a shallow depth. Almost everywhere, the stratification is fine. Young soils are calcareous throughout and mainly saline in the dry season. Older soils are noncalcareous and are only very slightly or not saline. The differences between soils are not significant.

Lower Meghna River Floodplain

The deposits of this region are mainly olive silt loams and silty clay loams. They occupy a somewhat irregular ridge and basin relief but with little difference in elevation between the highest and lowest parts. Ridge soils in the extreme south show patches which become slightly saline in dry season.

Chittagong Coastal Plain

This region occupies the plain land in greater Chittagong district and the eastern part of Feni District. It is a compound unit comprising piedmont, tidal, river and estuarine floodplain landscapes. This region includes six physiographic units such as piedmont planes, river floodplains, old tidal floodplains, young tidal floodplains and mangrove tidal floodplains. The inland part of the Bakkhali River comprises the river floodplain where the landscape is almost level and broad. There are floodplain ridges, inter-ridge depressions and small basins. Despite the compound nature of the area, soil conditions are relatively uniform over most of the area, with grey, near-neutral, silt loams and silty clay loams predominating.

Northern and Eastern Hills

Northern and Eastern Hills cover a series of northward plunging anticlines in the eastern hilly part of the region with scattered patches along the northern border of Jamalpur, Sherpur and Sylhet districts. The hills are formed with consolidated and unconsolidated sandstones, siltstones and shale of various Tertiary ages. The rocks have been uplifted, folded, faulted and dissected to form hill ranges or areas of complex hill and valley reliefs. Slopes are mainly very steep but the relief varies from very steeply dissected to gently rolling formations. Soil patterns are generally complex due to local differences in sand, silt and clay contents of the underlying sedimentary rocks.

High Ganges Floodplain

The High Ganges Floodplain covers the upstream of the Ganges from the Gorai off-take that covers a complex relief of broad and narrow ridges and inter-ridge depressions, separated by areas with smooth, broad bridges and basins. The upper parts of high ridges stand above normal flood level. The lower parts of ridges and basin margins are seasonally shallowly flooded, but some deep basin centers are moderately deeply or deeply flooded. There is an overall pattern of olive-brown, silt loams and silty clay loams on the upper parts of floodplain ridges and dark grey, mottled brown, mainly clay soils on lower ridge sites and basins. Most ridge soils are calcareous throughout. Some higher soils have non-calcareous upper layers of 30-60 cm. Non-calcareous layers are slightly acidic or neutral, but they are strongly acidic in some heavy basin clays.

Low Ganges River Floodplain

The Low Ganges River Floodplain covers the left bank of the Gorai River and extends up to Madaripur and Shariatpur districts. It covers a typical meander floodplain landscape of broad ridges and basins. Generally, there is some what irregular relief alongside rivers crossing the region, comprising broad and narrow ridges, inter ridge depressions and cut-off channels. Differences in elevation between ridge tops and basin centers are generally in the range of 3-5 m, but are less near the northern and southern boundaries. The general soil pattern is olive-brown silt loams and silty clay loams in the highest parts of floodplain ridges and dark grey silty clay loams to heavy clays in the lower sites.

Gopalganj-Khulna Beels

The downstream reach of the Madaripur Bill Route is located in the Gopalganj-Khulna Beels area, although the MBR feeds water to the beel area during pre-monsoon and drains out during post-monsoon. This physiographical unit occupies a number of low-lying areas between the Ganges River Floodplain and the Ganges Tidal Floodplain. Thick deposits of peat occupy perennially wet basins, but they are covered by clay around the edges and by calcareous silty sediments alongside the Ganges distributaries crossing the area. This is the largest peat stock basin of Bangladesh. The basins are deeply flooded by clear rainwater during monsoon.

Northern and eastern piedmont plains

This is a discontinuous region occurring as a narrow strip of land at the foot of the northern and eastern hills. This region comprises merging alluvial fans which slope gently outward from the northern and eastern hills into smooth, low-lying basins. In general, piedmont alluvium has much lower content of weatherable minerals than the adjoining Brahmaputra and the old Meghna alluvium. Locally at the foot of the northern hills, rivers bring in richer sediments which give some soils higher cation exchange capacities and cation contents. The grey terrace soils appear to be developed in older piedmont clays which have been uplifted by tectonic movements. Large parts of this region stand above normal flood-levels but they are subject to shallow flash flood and rainwater is retained on the surface within field bunds.

Old Meghna Estuarine Floodplain

Smooth, almost level, floodplain ridges and shallow basins characterize this floodplain. Relief is made irregular locally by man-made cultivation platforms in east of Chandina and in parts of Munshigonj, Sonagaon and Sariatpur.

Soils are relatively uniform within this region, both between adjoining ridges and basins, and between subregions. Silty soils predominate, but there are significant proportions of silty clay of clay basin soils in Dhaka, Madaripur-Gopalpur and Barisal.

Young Brahmaputra Jamuna Floodplain

This region has a complex relief of broad and narrow ridges, inter-ridge depressions, particularly infilled cut-off channels, and basins. Relief is most irregular in subregions. Basins are most extensive in Tangail and Dhaka. The difference in elevation between the tops of ridges and adjoining basins varies from 2 to 5 metres.

Grey floodplain soils predominate. These developed in the Brahmaputra alluvium which has mainly been deposited during the period since the river changed into its Jamuna channel about 200 years ago. Brahmaputra alluvium is rich in weatherable minerals especially biotite. Most of the soils have stratified alluvium below 50 cm.

Middle Meghna River Floodplain

This region includes islands – former Brahmaputra chars – within the Meghna River as well as adjoining parts of the mainland. It comprises various kinds of relief: low – lying basins with surrounding low ridges along river banks; areas with low ridges, inter- ridge depressions and old channels; and higher sandy ridges. The Meghna River banks are mainly stable, but bank erosion occurs locally, though on a small scale.

There are three main kinds of soils in this region. Grey loams and clays developed on ridges and basin in areas of Meghna alluvium. These soils occupy the greater part of the region. Grey loamy ridge soils and dark grey basin soils in included areas of Old Brahmaputra alluvium. Grey sands to loamy sands with compact silty topsoil, occupy areas of Old Brahmaputra char land which has been only shallowly buried by Meghna alluvium.

The study area covers all the hydrological regions except the St. Martin's Coral Island. The distribution of 29 agro-ecological regions in the six hydrological regions is presented in **Table 2.1** below.

Table 2.1: Agro-ecological region area in percent of hydrologic region

AEZ Name	North Central	North East	North West	River& Estuary	South Central	South East	South West
Active Brahmaputra-Jamuna Floodplain	5.0		1.1	37.1			
Active Ganges Floodplain	1.2		1.9	21.3	5.5		1.2
Active Teesta Floodplain			3.4				
Akhaura Terrace						1.1	
Arial Beel	1.0						
Chittagong Coastal Plain				0.4		3.6	
Eastern Surma-Kushiyara Floodplain		22.3					
Ganges Tidal Floodplain					49.8		36.4
Gopalgonj-Khulna Beels					2.0		8.2
High Barind Tract			5.0				
High Ganges River Floodplain			11.7				39.4
Karatoya-Bangali Floodplain			7.6				
Level Barind Tract			15.8				
Low Ganges River Floodplain	3.9		5.0	0.2	16.6		14.5
Lower Atrai Basin			2.7				
Lower Meghna River Floodplain				0.1		8.1	
Lower Punarbhaba Floodplain			0.4				
Madhupur Tract	26.7						
Middle Meghna River Floodplain	0.5	0.8		6.7		8.2	
North-Eastern Barind Tract			3.3				
Northern and Eastern Hills		11.3				4.7	
Northern and Eastern Piedmont	0.3	17.5				6.3	
Old Brahmaputra Floodplain	25.3	15.6		0.1			
Old Himalayan Piedmont Plain			12.2				
Old Meghna Estuarine Floodplain	2.9	8.1			5.0	48.4	0.4
Sylhet Basin		22.5					
Teesta Meander Floodplain			29.9				
Young Brahmaputra and Jamuna Floodplain	33.2	1.9		1.1			
Young Meghna Estuarine Floodplain				33.0	21.1	19.6	
Total	100	100	100	100	100	100	100

Source: CEGIS estimation from NWRD

2.4. Hydrological Setting of Bangladesh

Bangladesh is a riverine country. One of the world's biggest river systems like the Ganges, the Brahmaputra-Jamuna, the Padma and the Meghna rivers is flowing through the country to the Bay of Bengal. Most of the rivers are tributary or distributary of these major rivers. The entire country has been divided into eight hydrological regions based on National Water Management Plan, 2000 which is shown in **Figure 2.8**. The areas of all hydrological regions are presented in **Table 2.2** and this area is 0.4 percent larger than the Bangladesh Bureau of Statistics (BBS) data due to the definition of the sea-ward boundary. In the following chapters of this report all the regions have been discussed. However, the South-West and South-Central regions have been discussed together as their river systems are closely related and inter-linked. Theriver and estuary region has not been discussed separately in this report.

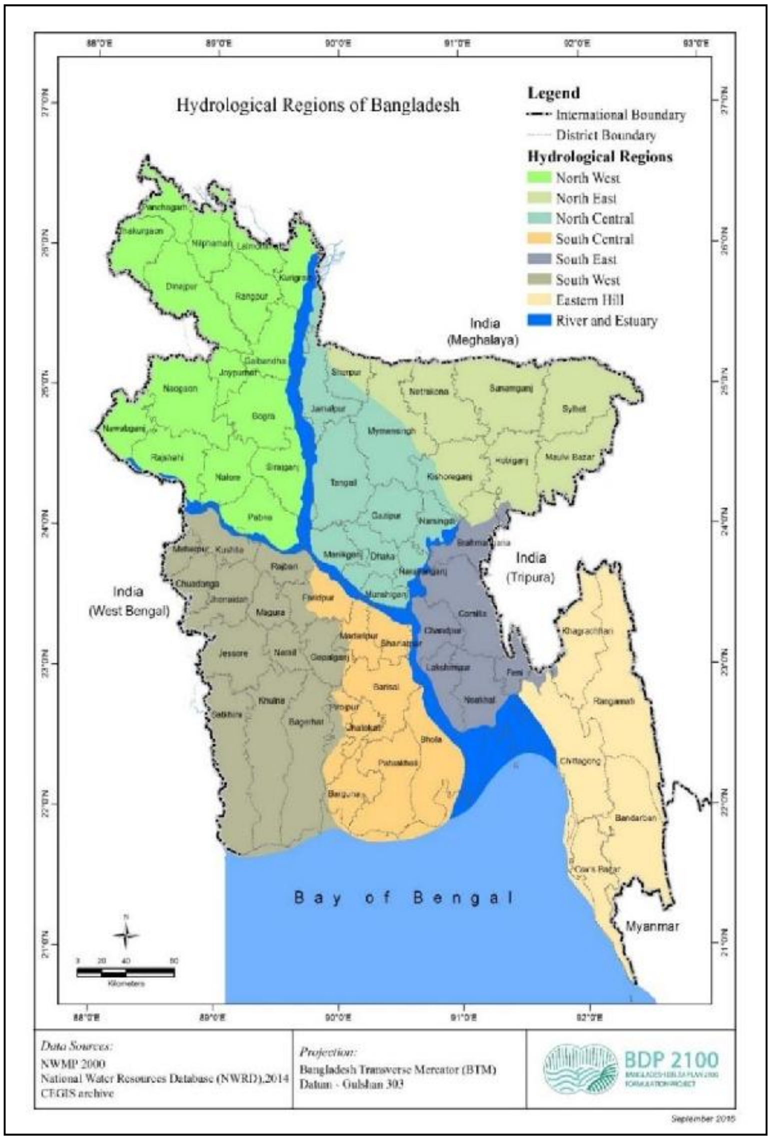

Figure 2.8: Hydrological regions of Bangladesh (NWRD 1998)

Table 2.2: Area-wise hydrological regions

Region	Gross Area (km^2)	Major rivers	Gross as % of total
North-West (NW)	31,606	Teesta, Dharala, Atrai, Dudhkumar	21.3
North-East (NE)	20,061	Surma, Kalni-Kushiyara, Dhanu	13.5
North-Central (NC)	15,949	Old Brahmaputra, Sitalakhya,Dhaleshwari, Buriganga	10.8
South-West (SW)	26,226	Garai, Kumar (Faridpur-Gopalganj), Bhairab-Kapatakhya	17.7
South-East (SE)	10,284	Titas, Dakatia	6.9
South-Central (SC)	15,436	Arial Khan	10.4
Eastern Hills (EH)	19,956	Karnafuli, Sangu, Bakkhali, Matamuhuri	13.5
Rivers and Estuaries (RE)	8,607	Brahmaputra-Jamuna, Ganges, Padma and Meghna	5.8
Total	**148,125**		**100%**

3. Geo-morphological Characteristics of the Major Rivers

3.1. Evolution of River System

The Ganges-Brahmaputra-Jamuna-Meghna system built this Bengal Delta, one of the largest in the world. The Ganges, Padma, Brahmaputra-Jamuna, Upper Meghna and Lower Meghna are the major rivers of Bangladesh. For this study the major river system has been considered as combined systems of the Ganges-Padma, Brahmaputra-Jamuna and Meghna river systems. The river system of this delta has evolved through various changes and these changes are interlinked with each other. In line with the evolution of the river system, the rivers during the last 250 years have changed their respective courses several times (**Figure 3.1**). The rivers abandoned their courses and subsequently, occupied several other new courses. In most of the cases, delta building processes, together with tectonics and natural hazards, like earthquake played the main role for frequent avulsion and shifting processes of the rivers. Due to sediment starvation most of the large deltas of the world are suffering from net erosion, while net accretion is the dominating morphological process in the Bengal Delta.

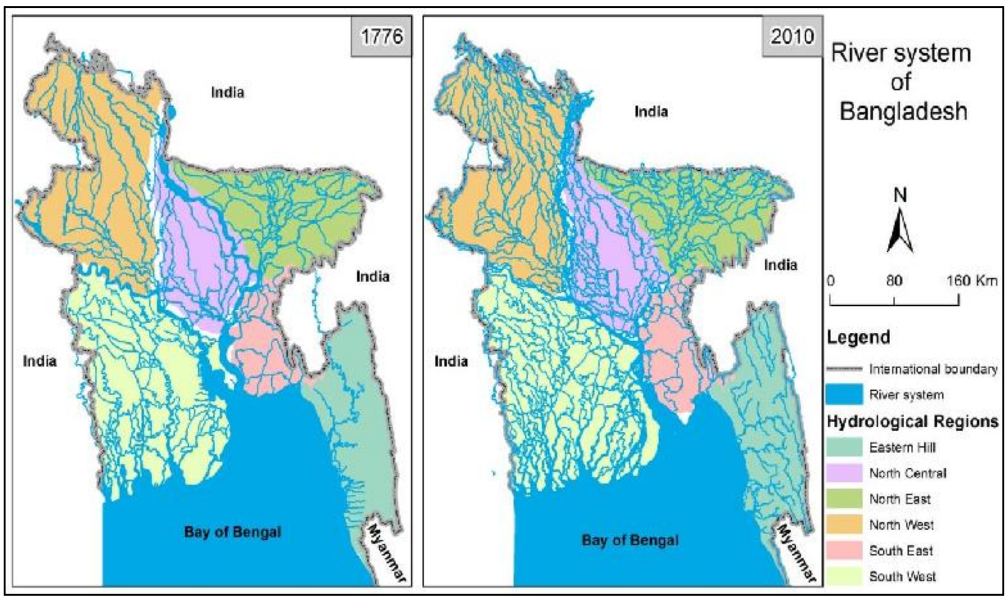

Figure 3.1: River system of Bangladesh in 1776 and 2010 (CEGIS 2010)

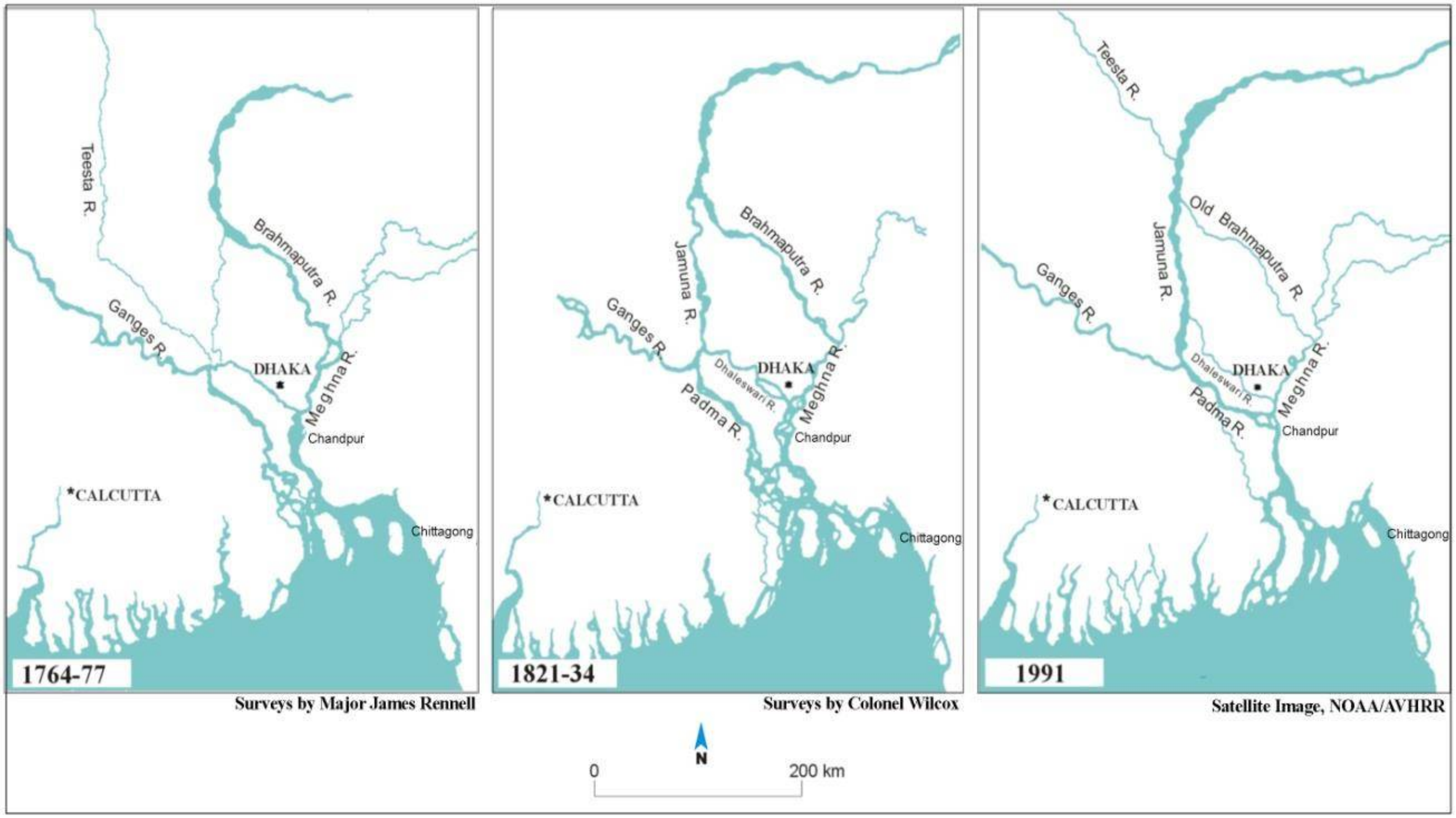

Figure 3.2: Development of the main rivers in Bangladesh over time

About 250 years ago, the Brahmaputra River flowed through the east side of the Madhupur Tract to the meet the Meghna River and finally fell into the Bay of Bengal keeping Bhola district at its west (**Figure 3.2**). Moreover, the Ganges flowed by the side of Aricha and then along the present course of the Arial Khan River and out-fell into the Bay keeping Bhola District at its east. The Jennai River was found taking off from the Brahmaputra River to meet the Ganges. Huge water and sediment were carried through the Brahmaputra to the northeast region.

About 200 years ago, a significant amount of the Brahmaputra flows diverted to the present Jamuna River to meet the Ganges due to the avulsion of the Teesta River and other tectonic activities. Two courses, namely the Jennai and the Konai rivers, after taking off from the Brahmaputra River, joined together and taking the name "Jamuna" met with the Ganges River at what was then Jafarganj (presently Daulatpur). The combined flow met the Meghna River at Chandpur under the name "Kirtinasha". Since then, the northeast region has been starving for sediment. Consequently, the confluence of the Jamuna River with the Ganges had led to major increases in the volume of runoff, flood peaks and sediment load.

By the early 20th century, most of the Brahmaputra flow was diverted to the Jamuna River and most of the Padma flow was diverted to the Meghna River turning its old course, along the Arial Khan River, into its right bank distributary. Since then the Arial Khan River has been hydro-morphologically deteriorating. Due to the avulsion of the Brahmaputra to the Jamuna, the Upper Meghna River has become a morphologically inert river and as the Sylhet Basin is subsiding due to sediment deficit, the basin is subsiding more on its north most side. As a result, the rivers in the northeast region are found to have a tendency to move to the north. When they fall into the deep basin, they flow to the south from the north against the terrain slope.

The avulsion and evolution of the major river system of Bangladesh has profound impact on the characteristics of the other rivers as well as the development of the river system of the whole country.

3.2. Hydro-morphological Characteristics of Major Rivers

Bangladesh consists mainly of riverine and deltaic deposits of three large and extremely dynamic rivers entering the country: the Brahmaputra, Ganges and Meghna rivers. The major rivers of Bangladesh influence the hydrological and morphological characteristics of other rivers significantly. Thus, any changes in the main river becomes the drivers which may influence the overall socio-economic condition of the country. Bangladesh is tectonically and seismically active and affected by different natural events and human intervention beyond its borders due to its geographical setting. The huge sediment load coming from upstream is mainly carried by the major rivers of the country (**Table 3.1** and **Table 3.2)** and thus, these rivers are morphologically very active. The width, length and discharge of the major rrivers are given in **Table 3.3** and the parameters estimated to classify the planform characteristics is shown in **Table 3.4**. These rivers play an important role in transporting goods and carrying passengers. They are also impotant source of water supply, irrigation and flushing the pollutants. Annually these rivers erode several thousand hectares of floodplain land leaving thousands of people homeless and damaging or destroying infrastructure (**Figure 3.3** and **Table 3.5** to **Table 3.8**). The description of the major river system is given in the following sections.

The bed material transport generally determines the morphology of the fluvial dominated reaches of the river. This fraction of sediment reduced both in the Jamuna and the Ganges rivers from 1960 to 1990s and subsequently in the Padma and Lower Meghna. Due to increase of wash (silt+clay) load total sediment supply to the bay rather increased during that period. The reducton of bed material causes change of the river behavior, such as increased width and annual rate of bank erosion during the same period.

Figure 3.3: Major rivers of Bangladesh with erosion and navigation characteristics (CEGIS, 2014)

Table 3.1: The annual average sediment load as measured during 1966-1969 by the BWDB (source Delft Hydraulics/DHI, 1996c)

Period	Type of sediment	Jamuna	Ganges	Padma
1966-1969	$S_{wash\ load}$ (m ton/y)	332	330	498
	$S_{susp.\ bed}$ (m ton/y)	221	164	257
	Total S_s (m ton/y)	553	494	755

Table 3.2: Average annual sediment load based on the sediment measurement of FAP 24 from 1994-96

Period	Type of sediment	Jamuna	Ganges	Padma
1994-1996	$S_{wash\ load}$ (m ton/y)	277	558	721
	$S_{susp.\ bed}$ (m ton/y)	125	76	227
	Total S_s (m ton/y)	402	634	948

Table 3.3: Width, length and discharge of major rivers (Rivers of Bangladesh 2010)

Name	Average width (km)	Length (km)	Low discharge (cumec)	Peak discharge (cumec)	Type
Jamuna	12	230	3430	102535	Braided
Ganges	5	269	530	70868	Braided
Padma	10	121	3040	14200	Braided
Upper Meghna	3.4	156	2	19900	Anastomosing
Lower Meghna	1.1	65			Anastomosing

Table 3.4: Parameters estimated for the river to classify the planform characteristics

River	Planform	Q_b(m^3/s)	B (m)	h (m)	i (cm/km)	u (m/s)	B/h
Jamuna	Braided	48,000	4,213	6.6	7.5	1.70	630
Ganges	Braided	43,000	3,718	6.5	5.0	1.78	571
	Constricted	43,000	2,476	6.9	5.0	2.51	357
Padma	Braided	75,000	5,200	7.5	4.5	1.93	695
	Constricted	75,000	3,867	8.0	4.5	2.42	483

Source: River Survey Project, Special Report no. 7, FAP 24

Note: Q_b = Bankfull Discharge (m^3/s), B = Bankfull Width (m), h= Height (m), i= Overall water surface slope (cm/km), u= velocity (m/s), B/h = aspect ratio

Table 3.5: Bank erosion and accretion along the Jamuna River during the period 1973 – 2014 (CEGIS, 2014)

District	Eroded area (ha)	Accreted area (ha)
Kurigram	18,479	165
Gaibandha	9,348	983
Jamalpur	10,608	5,617
Bogra	10,938	5,010
Sirajganj	22,784	4,633
Tangail	9,150	30
Pabna	2,725	2
Manikganj	6,335	4
Total	**90,367**	**16,444**

Table 3.6: Bank erosion and accretion along the Ganges River during the period 1973 – 2014 (CEGIS, 2014)

District	Eroded area (ha)	Accreted area (ha)
Nawabganj	4,693	10,785
Rajshahi	1,670	1,716
Natore	2,045	121
Kushtia	11,857	1,570
Pabna	2,203	8,295
Rajbari	7,373	2,522
Total	29,842	25,009

Table 3.7: Bank erosion and accretion along the Padma River during the period 1973 – 2014 (CEGIS, 2014)

District	Eroded area (ha)	Accreted area (ha)
Manikganj	6,830	
Rajbari	473	347
Faridpur	7,780	4,956
Dhaka	2,460	-
Munshiganj	5,958	57
Madaripur	1,308	3,460
Shariatpur	8,420	2,726
Total	**33,229**	**11,545**

Table 3.8: Bank erosion and accretion along the Lower Meghna River during the period 1973 – 2012 (CEGIS, 2012)

District	Eroded area (ha)	Accreted area (ha)
Barisal	8,953	10,470
Bhola	4,112	1,234
Chandpur	7,608	4,463
Lakshmipur	3,595	3,702
Shariatpur	1,553	2,396
Grand Total	**25,820**	**22,265**

3.2.1. The Brahmaputra-Jamuna River

The Brahmaputra-Jamuna is one of the largest braided rivers on earth and still in the process of development and as such, the river is highly unstable. It has two distinct reaches within Bangladesh. The upstream reach from its entry into Bangladesh to the off-take of the Old Brahmaputra River upstream of Bahadurabad is called the Brahmaputra which only receives waters from its tributaries like Dudkumar, Dharla and the Teesta. From there up to its confluence with the Ganges at Aricha, it is called the Jamuna River. In this reach there are numbers of distributaries along its left bank.

Between 1914 and 1953, the river continued its westward migration while widening significantly and metamorphosing its planform from meandering to braiding (**Figure 3.4** and **Figure 3.5**). By 1973, the average width of the river had reduced slightly, but rapid westward migration had continued. Between 1973 and 1992, the rate of increase of the average width accelerated to a very high level, although the rate of westward migration slowed down. During the last four decades, the rate of widening has been particularly high while the rate of centerline-westward migration has slowed, effectively to zero. Instead of the centerline, the rate of right bank migration determines the rate of right bank erosion and widening. The westward migration of the right bank is highly important to the people living on the adjacent floodplain along right bank.

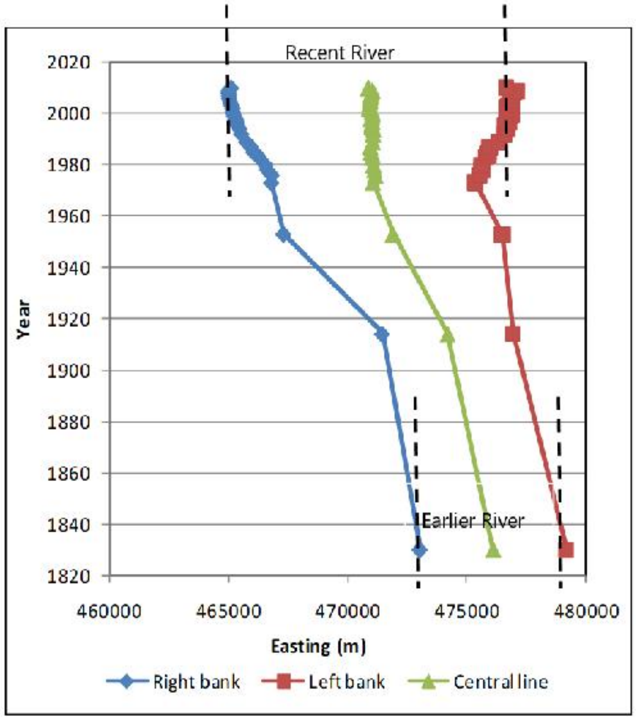

Figure 3.4: Lateral movement of the length-averaged bank lines and centerline of the Jamuna River 1830 – 2010

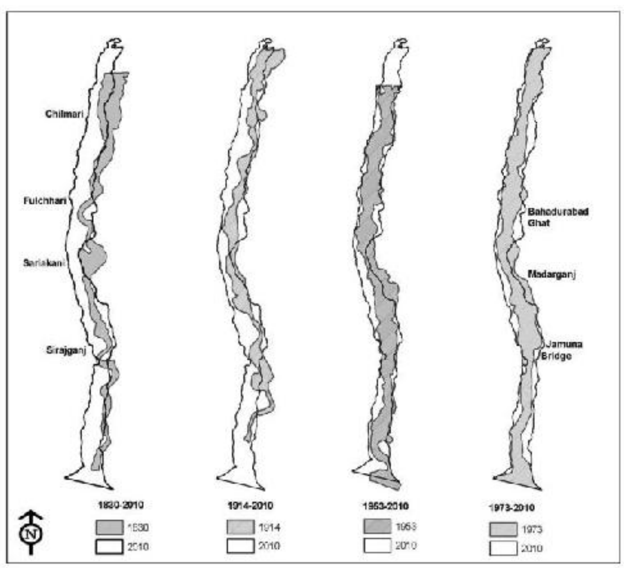

Figure 3.5: Bankline migration of the Jamuna River 1830 – 2010

Erosion has been the dominating morphological process in this river during the last few decades (Figure 3.5). During1973-2014 period, a large amount of floodplain (90,367ha) has been eroedby the river, with only a small amount of land (16,444ha) has been accreded (**Figure 3.6**). Annual river bank erosion was very high in the 1980s (about 5,000 ha/y) when the rate of widening of the river was very high (**Figure 3.7**). During the first decade of this century, the annual rate of riverbank erosion dropped to 2,000 ha/y. The rate of rapid drop in riverbank erosion was partly contributed by the natural processes and partly due to human intervention starting with the construction of major riverbank protection schemes during the mid-1990s.

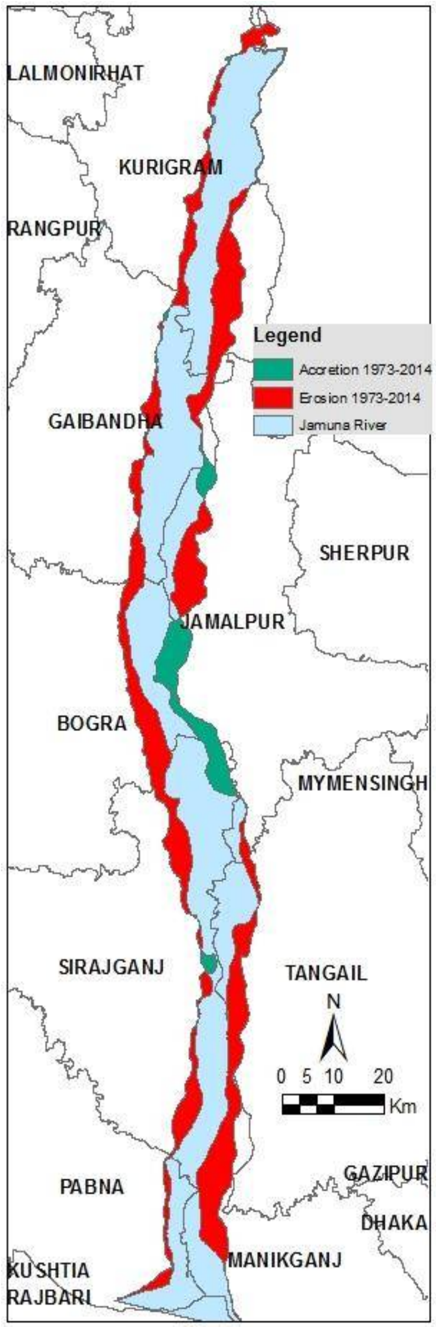

Figure 3.6: Erosion-accretion along the Jamuna during 1973-2014 (CEGIS 2014)

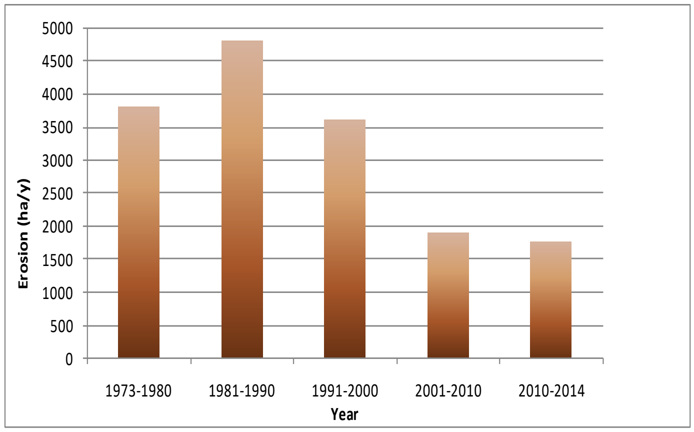

Figure 3.7: Rate of river bank erosion of the Jamuna River

The Jamuna River occupies a huge space which may not be required to transport water and sediment imposed on it without substantially changing its dimensions. The people of the country do not have a very pleasent experience with the river as it is responsible for severe events of erosion. Due to its braiding and dynamic characteristics, navigability of this river could not be used properly. However, the situation can be improved and the country can reap much benefit if the river could be well-managed. A properly managed Jamuna may facilitate in reclaiming land, protect from riverbank erosion, enhance navigability and develop new commercial centers, industrial parks and cities along both its banks. It is, therefore, imperative to manage the Jamuna to alleviate poverty and develop economic growth over a large area.

3.2.2. The Ganges River

The Ganges is a very dynamic river of Bangladesh. The total length of the Ganges is about 2,200 km but only the lower 220 km is in the territory of Bangladesh. The catchment area of the river is about one million sq. km, where more than 400 million people are living, currently. The Ganges is also a large meandering river with alternating expansions and contractions. At the very wide expansions, the pigeon-belly-shaped bends demonstrate a braided nature with multiple constituent shallow and deep channels separated by sandy islands.

After the commencement of the Farakka Barrage in India, the drastic reduction of annual dry season flow and discharge in the mid 1970s have been observed mainly due to the flow diversion by the barrage. The sediment load of the river is about half a billion ton per year.

Width of different reaches of the Ganges depends on the phase of meandering bend development (**Figure 3.8**). This development along left bank is often restricted by its cohesive banks. Inside Bangladesh, the Hardinge Bridge divides the Ganges into two separate reaches. It is found that the width of both the reaches changed over time (**Figure 3.9**). The width of the lower reach (downstream of the Hardinge Bridge) has been found to be lower than that of the upper reach (upstream of the Hardinge Bridge) as shown in Figure 3.9. This might be due to the presence of natural (relatively less erodible bank materials) and man-made (river-training structures related to the construction of Hardinge Bridge) controls at the lower reach. In the recent past, the widths of both reaches of the river have become stable. The development of meandering bends and chute cut-offs in the recent past indicate that the reach-averaged width of the upper reach might be reduced in the near future.

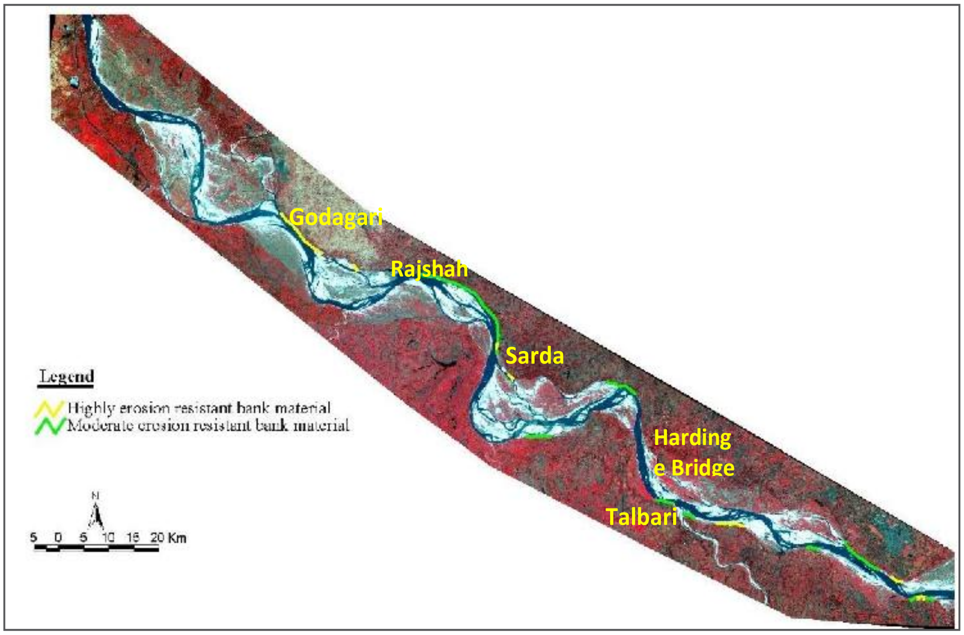

Figure 3.8: Natural controls along the banks of the Ganges River (CEGIS, 2003)

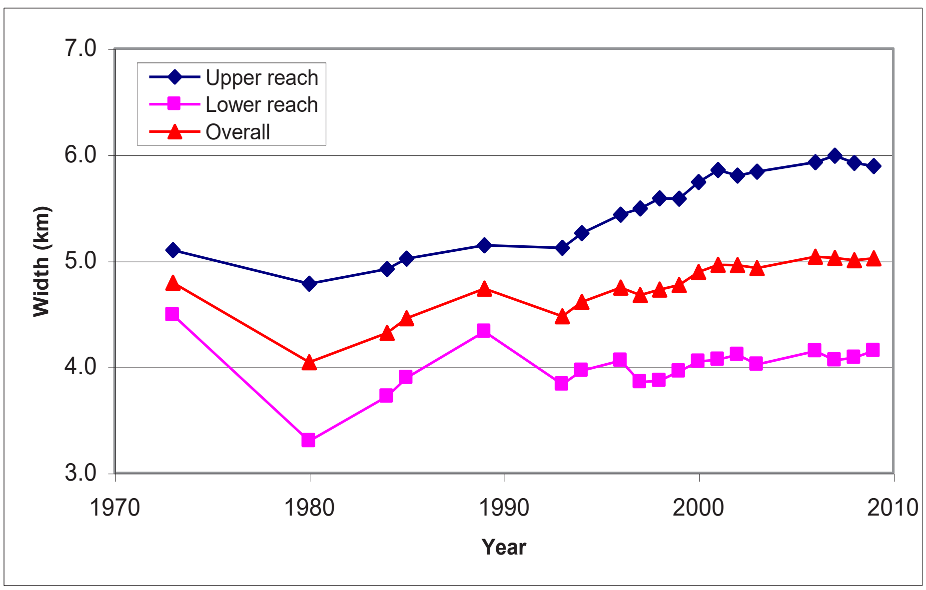

Figure 3.9: Change of width of the Ganges River over time

People living along the adjacent floodplain of the country have to suffer from river bank erosion and flooding Meandering bend development along the right bank of the Ganges, being very rapid and aggressive, may cause the erosion of several hundreds of ha in a year. These bends are formeddue to the erosion of unconsolidated loosely packed materials. In the 1980s and 1990s, the annual rate of riverbank erosion was very high as the large meandering bends were in the development phase at that time. In the recent past, chute cut-off had occurred at these bends, which facilitated to intervene in the system without providing much effort (**Figure 3.10** to **Figure 3.12**). During the period of 1973-2014 period, the total erosion of the Ganges River was 27,842ha and total accretion of land was 25,009 ha (**Table 3.6**).

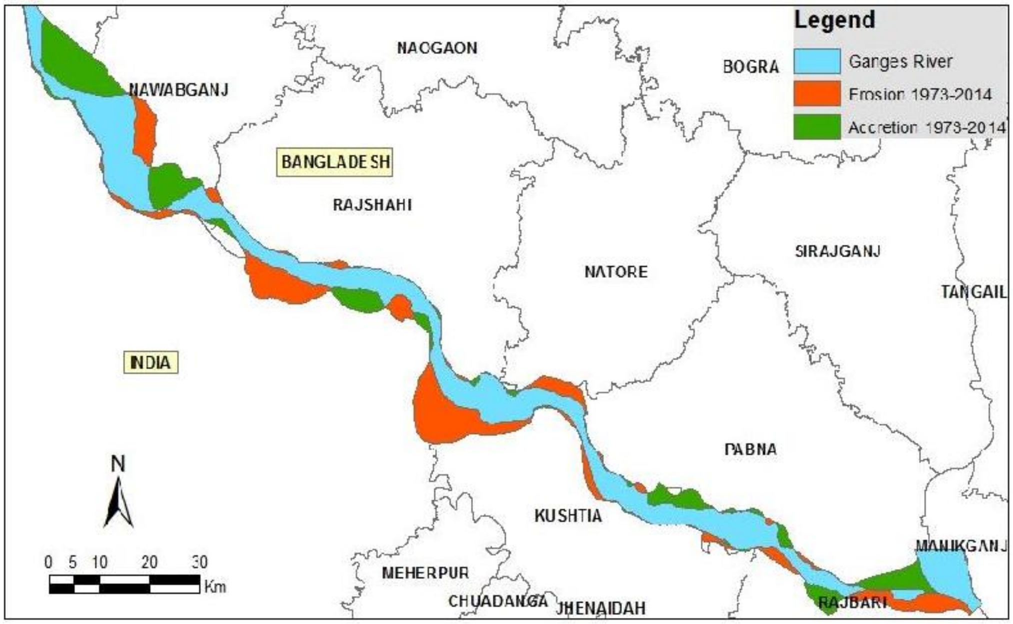

Figure 3.10: Erosion-accretion along the Ganges River during the period 1973-2014 (CEGIS 2014)

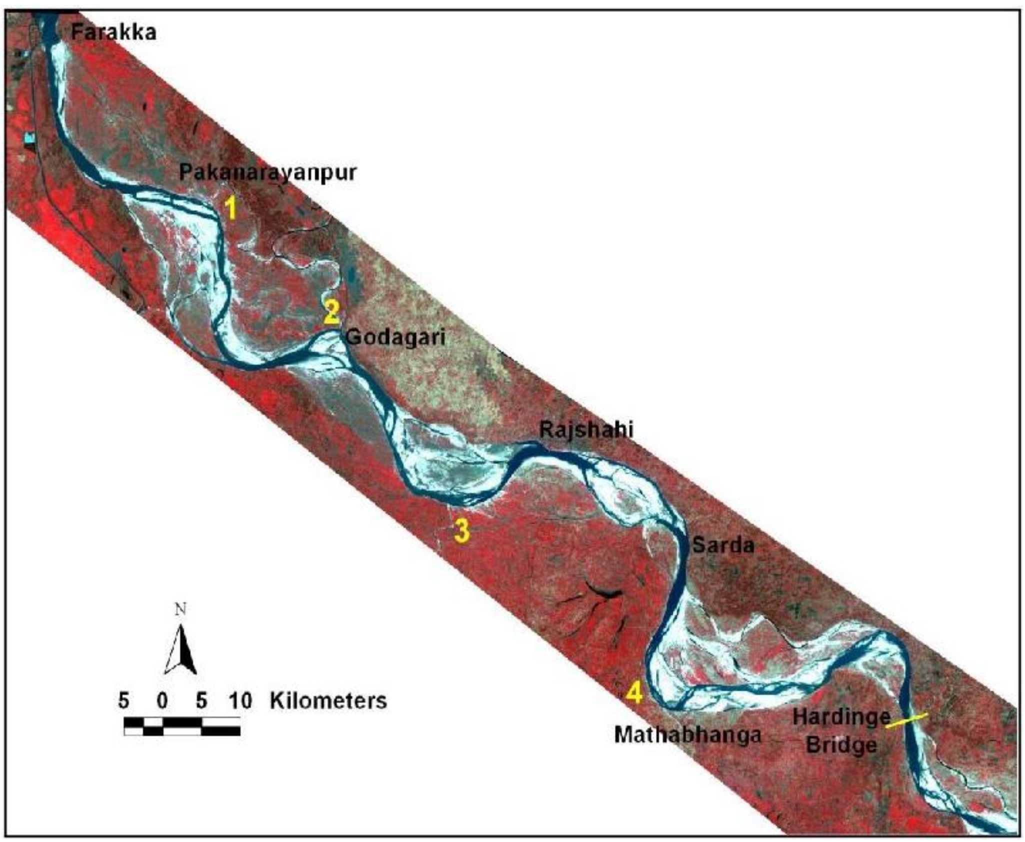

Figure 3.11: Satellite image showing the identification of different bends.

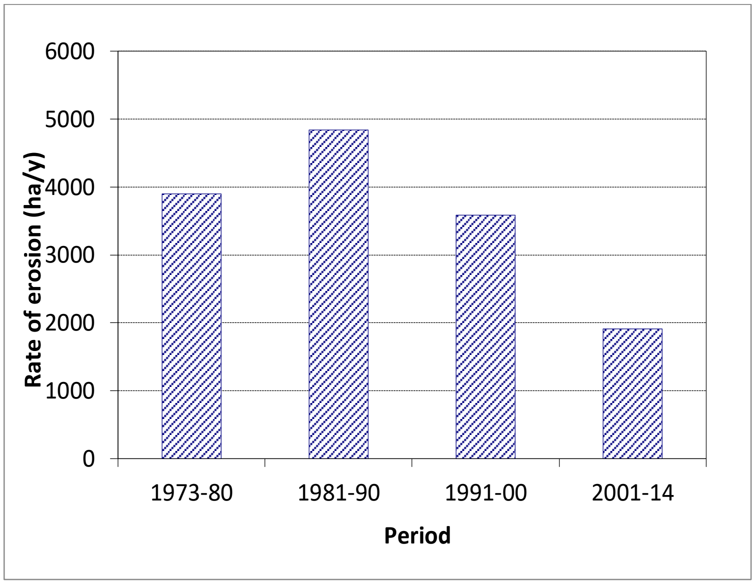

Figure 3.12: Rate of erosion along the Ganges River during different periods

Unlike the Jamuna, the characteristics of the bank materials along the Ganges are not homogeneous. Less erodible bank materials are present at several locations along the left bank of the Ganges (Figure 3.8). Regime width and depth vary from naturally constricted reaches to the reaches where bank materials are highly susceptible to erosion. Navigability of this river is poor. However, the situation can be improved by appropriate river management. A well managed Ganges could facilitate reclaimation of land, provide protection against riverbank erosion, enhance navigability, and develop new commercial centers, industrial parks and cities along both its banks and enhance the environmental/ecological condition, particularly in the SW and SC regions and the Sunderbans area.

3.2.3. The Padma River

The Padma River is the combined flow of the Jamuna and the Ganges rivers stretching from Aricha to its confluence with the Meghna River near Chandpur. Like the the Jamuna and the Ganges, the Padma is also highly dynamic. The river shows braided and straight patterns through intermediate meandering state, both spatially and temporarily. During the last few decades, the Padma River has changed its planform causing erosion and accretion, resulting into sufferings of the floodplain dwellers and national loses. The present course of the Padma River is relatively new- less than 200 years before the combined flow of the Jamuna and Ganges rivers named as the Padma River, broke through (sometime between 1830 to 1960) the old alluvium (named as Chandina Alluvium by GSB, 1990) and met with the Meghna River near Chandpur. Since then, the river's course has started to shift in the northeast direction. The rate of shifting has been impeded by the existence of patches of less erodible bank materials along its right bank.

The catchment area of the Padma River is 1.57 million km^2, which is equal to the sum of the catchments of the Jamuna and the Ganges. The flow of the Padma is mainly due to the southwest monsoon precipitation, which is concentrated in the period of June to October. During the rest of the year, the flow is generated from the base flow and snow melting in the Himalayas. Therefore, the difference between monsoon and dry season flow is very high.

During the last few decades, the Padma River has changed its planform from braided to straight through meandering and back. At present, the length averaged width of the river is about 10.5 km. The annual rate of riverbank erosion is very high – several thousand hectares per year, which causes several thousands of people to suffer every year (**Figure 3.13**). The banks of the Padma can be divided in two classes depending on erodibility (**Figure 3.14**). The bank erosion characteristic of less erodible banks is different from that of highly erodible banks. The annual maximum erosion rate may exceed 1,000 m/y in case of highly erodible bank materials, whereas the maximum erosion rate may be limited within a few meters per year in the case of less erodible bank materials. Figure 3.14 shows the location of highly erodible and less erodible bank materials along both banks of the river. During the period of 1973-2014, the bank erosion and accretion was 33,229ha and 11,545 ha respectively (**Table 3.7**).

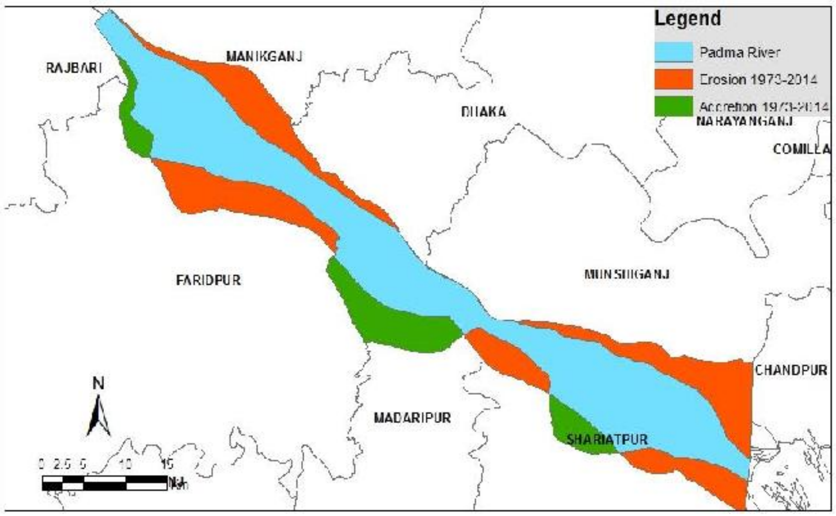

Figure 3.13: Erosion along the Padma River (CEGIS 2014)

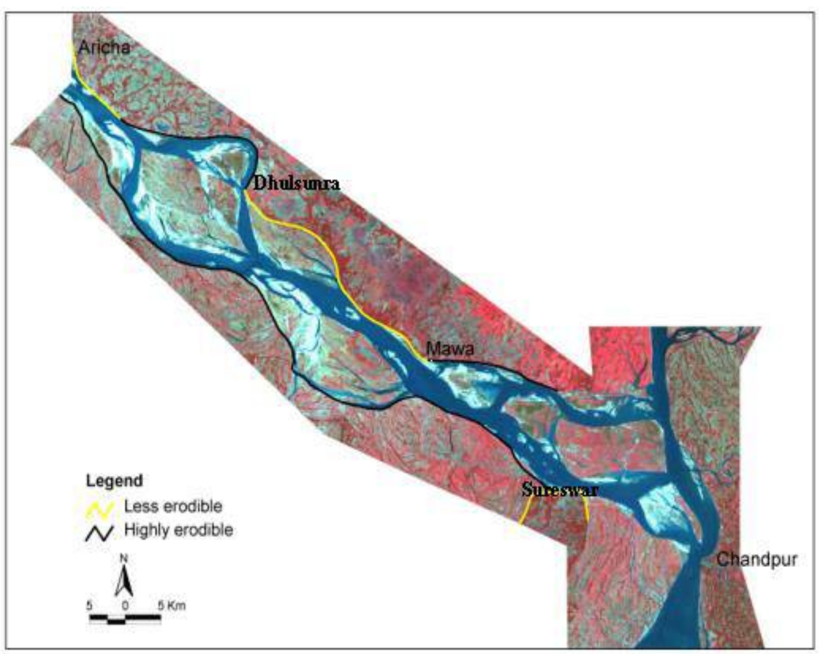

Figure 3.14: Location and extent of less and highly erodible bank materials along the Padma River (CEGIS, 2005)

3.2.4. The Meghna River

Originating from Surma-Kushiyara river system, the Meghna River flows through the eastern part of Bangladesh and discharges into the Bay of Bengal. The part of the river up to the confluence with the Padma River is known as Upper Meghna whereas the remaining part is known as the Lower Meghna (Figure 3.3).

The Upper Meghna is an important river of Bangladesh, being a drainage outlet for the North-Central, North-East and the South-East regions. It is one of the rivers, jointly building the Bengal Delta. Upper Meghna River can be better classified as an Anastomosing (multi-threaded low energy) river and its planform is quite stable. The Upper Meghna River is flowing on the previous bed of the Old Brahmaputra, but with much smaller discharges, and has thus, turned out as an underfit river. Unlike other major rivers, process of erosion and accretion in this river is slowand most of the reaches accretion is the dominating morphological process.

In the Upper Meghna River, the flow area has increased from upstream to downstream. Generally, flow area increases from upstream to downstream in a dying tidal river. That means Upper Meghna River is declining and this process will continue in future. Moreover, if sea level rises due to climate change effect, the bed level of Meghna River will not rise due to less sediment supply from upstream. Navigation facility is available along the whole Upper Meghna River during both dry and wet season. Due to its stable characteristic and navigation facilities, the areas along the river possess immense opportunity of development as industrial arena.

On the other hand, the Lower Meghna River is a very dynamic. In terms of water flow volume, the Lower Meghna River is ranked third in the world. Almost the total flow of the Ganges-Brahmaputra-Meghna (GBM) basin runs through this river and carries a huge amount of sediment. Bank erosion and frequent char development are the main problems of this river (**Figure 3.15**). The river erodes its bank when any char develops and creates obstruction to the flow. Thus, riverine chars dominate the morphology of this river.

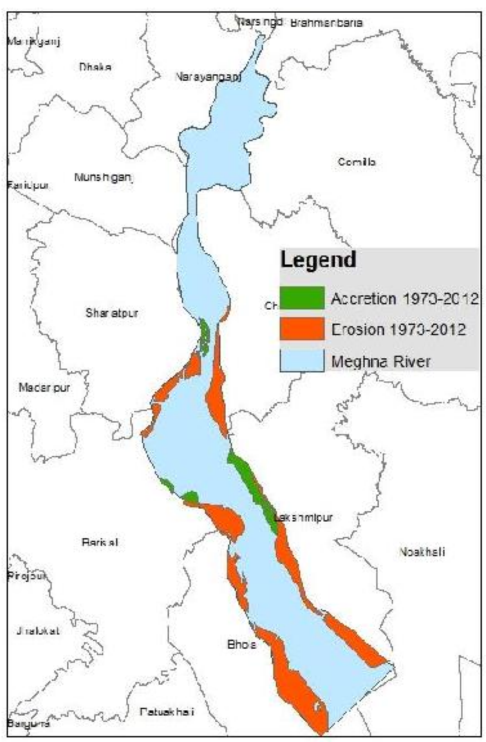

Figure 3.15: Erosion along the Meghna River (CEGIS 2012)

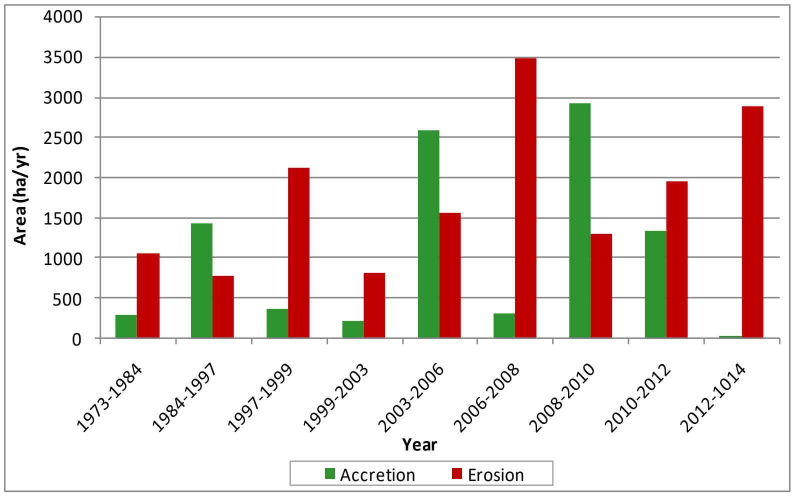

Figure 3.16: Temporal variation of erosion and accretion along the Lower Meghna

The Lower Meghna River is included in the Bangladesh Inland Water Transport Authority (BIWTA) navigational routes as a Class-I Route as it is a very important route. Large ships and cargo vessels ply in this river regularly and the width and depth of this river are sufficient for such vessels. Erosion and accretion of the Lower Meghna during 1973-2014 was 25,820 ha and 22,265 ha respectively (Table 3.8).

4. Geo-morphological Characteristics of Regional Rivers

4.1. North-West Region

4.1.1. Geographical Setting

The North-West Region is the largest hydrological region by its area. Presently, this region consists of eight districts of the Rajshahi Division and nine districts of the Rangpur Division of Bangladesh. The region is bounded by the Ganges River on the south and the Brahmaputra-Jamuna River on the east (**Figure 4.1**). These two mighty rivers contribute the maximum flow to the country. Including the Ganges and the Jamuna rivers, there are about 115 rivers in this region. Among them, Atrai, Teesta, Dharala, Dudhkumar, Karatoa, Mahananda, Bangali are the major rivers. The Rangpur Division is inclined to the southeast and thus, some rivers of this region are found flowing towards the Teesta River and others towards the Jamuna River. The Barind Tract at the west side of Rajshahi Division makes the area elevated, and the elevated riverbanks of the Jamuna and the Ganges make the region basin-shaped where Chalan Beel is located. Most of the rivers of this area come from the Ganges River and Barind Tract, and outfall into the Brahmaputra-Jamuna River (BWDB, 2011).

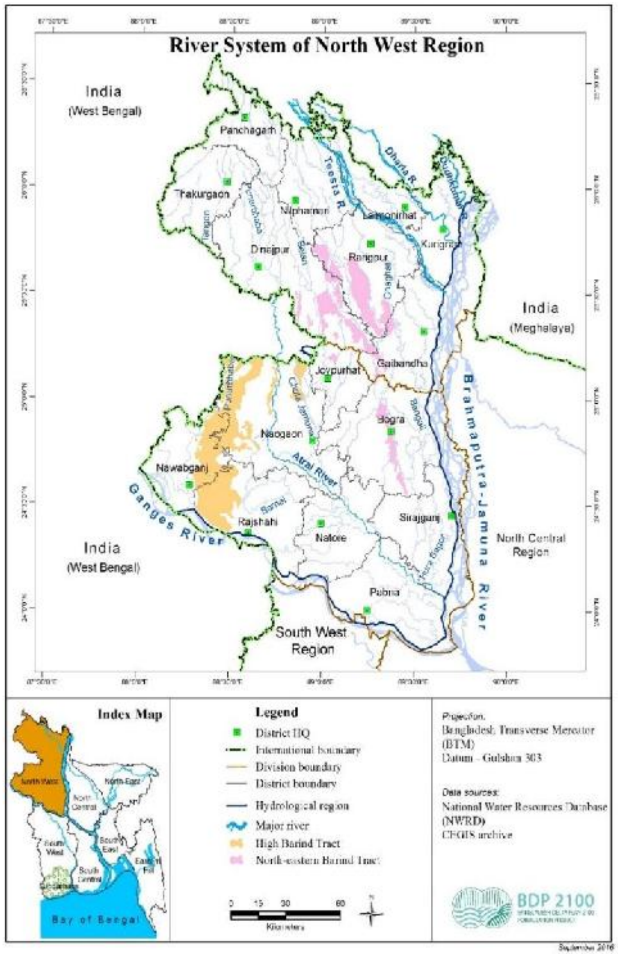

Figure 4.1: Rivers in the North-West Region

4.1.2. Topographical setting

A large area of depressions or beels exists in the southern part of this region. This area is collectively called 'Chalan Beel'. In the monsoon, the area acts as a huge flood retention reservoir. The main sources of inflow into the region are runoff from local rainfall and spilling from the large bordering rivers, particularly the Jamuna and the Teesta. The Upper Karatoya-Atrai-Baral and the Jamuneswari-Karatoya-Bangali are the two main river systems draining the greater part of the North-West region. These two river systems drain into the Hurasagar River. Rivers in the northern part, are mostly cross-border rivers and flashy in nature. Except the Mohananda all other rivers drain into the Jamuna River, so their drainage and downstream condition is governed by stage of the Jamuna River. The drainage pattern in the middle part of the North-West area is complex in nature. The Atrai-Baral basin is characterized by flat topography in its southern part and slightly steeper ground in the north and northwest. The areas between these rivers comprise the inter-fluvial depression of the Chalan Beel, which conveys significant floodplain flows during the monsoon.

The surface profile of the east-west section NW-1 (**Figure 4.2**) indicates that the highest peak of 42 mPWD is at 356 km where the Dhepa river is flowing (**Figure 4.3**). The Punarbhaba River is flowing in the lowest valley level at 37 mPWD and the Karatoya River is flowing at the level of 39 mPWD. The land slope of the Teesta River

Floodplain is about 16 cm/km with conveying rivers of Ghagat, Burail, Teesta and Dharala. The surface profile of section NW-2 specifies the level of the Barind Tract at 40 mPWD. The high Ganges floodplain is located at west of the Barind Tract and leveled more than 22 mPWD. Rest of the parts have some undulation from 13 to 15 mPWD. The Karatoya River at Nilphamari is flowing on a level of 16 mPWD. The section from 374 km to 408 km in section NW-3 is more elevated than that of section NW-2. The Atrai River flows in the lowest level of the basin. The surface profile of section NW-5 indicates that the land slope from 697 to 878 km northing is 20 cm/km. The locations of several rivers in this region are shown in the long profile (Figure 4.3 and **Figure 4.4**). After the sloping, land levels vary in between 10 to 12 mPWD.

The Barind Tract and the Atrai basin, a part of the Chalan Beel, are the controlling features for land and river development in this region. Another north-south natural boundary of this region is the right bank of the Jamuna River.

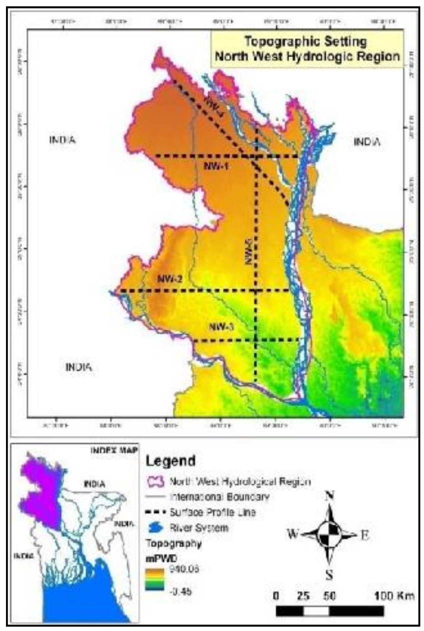

Figure 4.2: Topographical setting of North- West Region

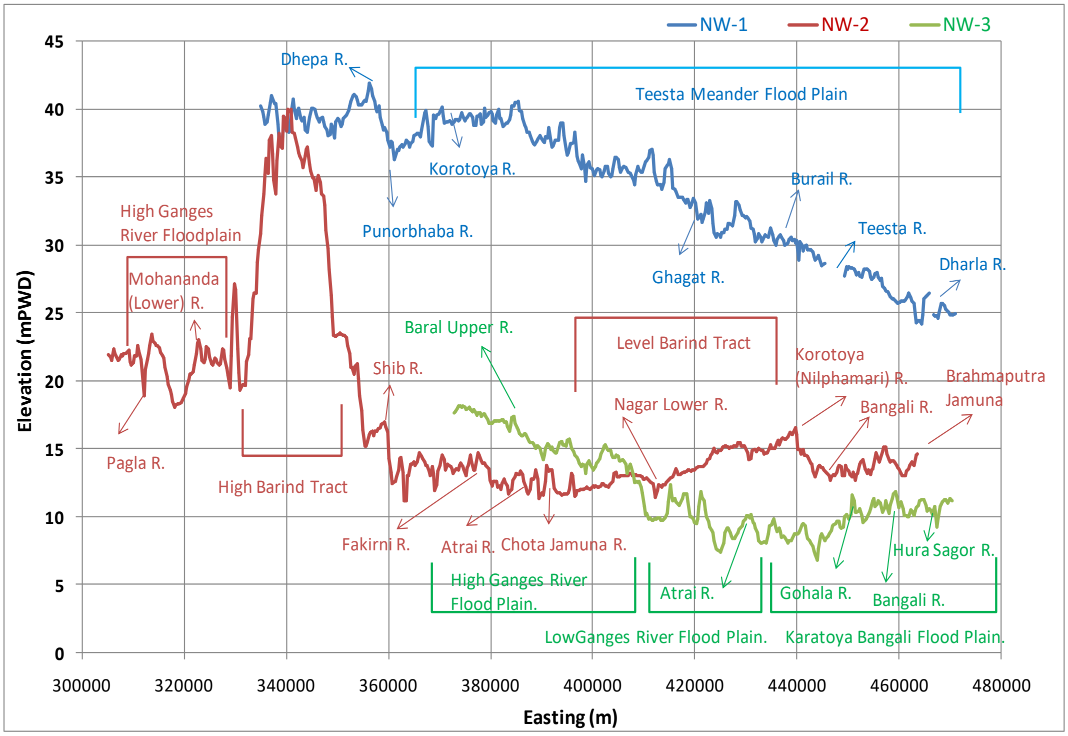

Figure 4.3: East west surface profiles in North-West Region of Bangladesh

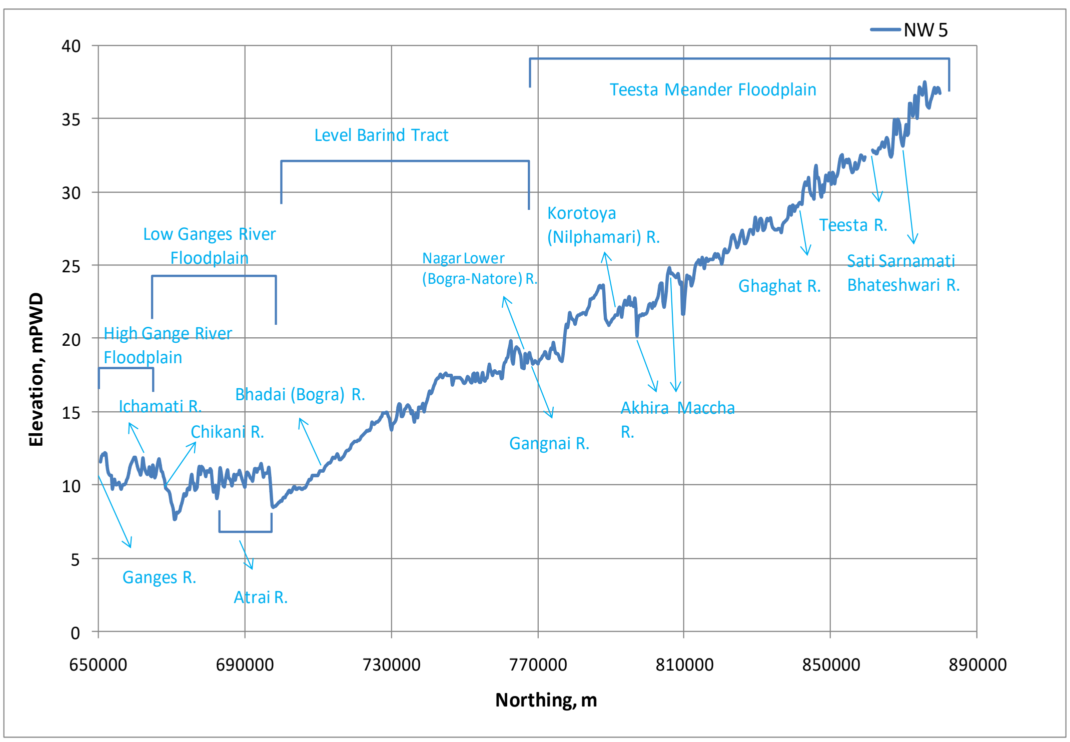

Figure 4.4: North south surface profiles in North-West Region of Bangladesh

4.1.3. Historical Development and Problems

The river system and characteristics of this region have gone through major changes due to the avulsion of the Teesta River. At the end of the 18th century, the main flow of the Teesta flowed along the present course of the Atrai-Karatoya River to meet the Ganges after passing through Chalan Beel (**Figure 4.6**). By the early 19th century a new course of the Teesta River, mainly triggered by a big flood in the Teesta catchment, evolved to meet with the Brahmaputra River. This avulsion influenced other changes in the river system of this region and considered to be one of the reasons for avulsion of the Brahmaputra River. Since the avulsion of the Brahmaputra River, it shifted toward the west (Figure 3.5). This phenomenon also has impact on the characteristics of this region. Many distributaries of the Teesta River have been abandoned due to the construction of the Teesta Barrage in India and Bangladesh. Thus, human intervention is an important issue for this region affecting the hydro-morphological regimes of the rivers.

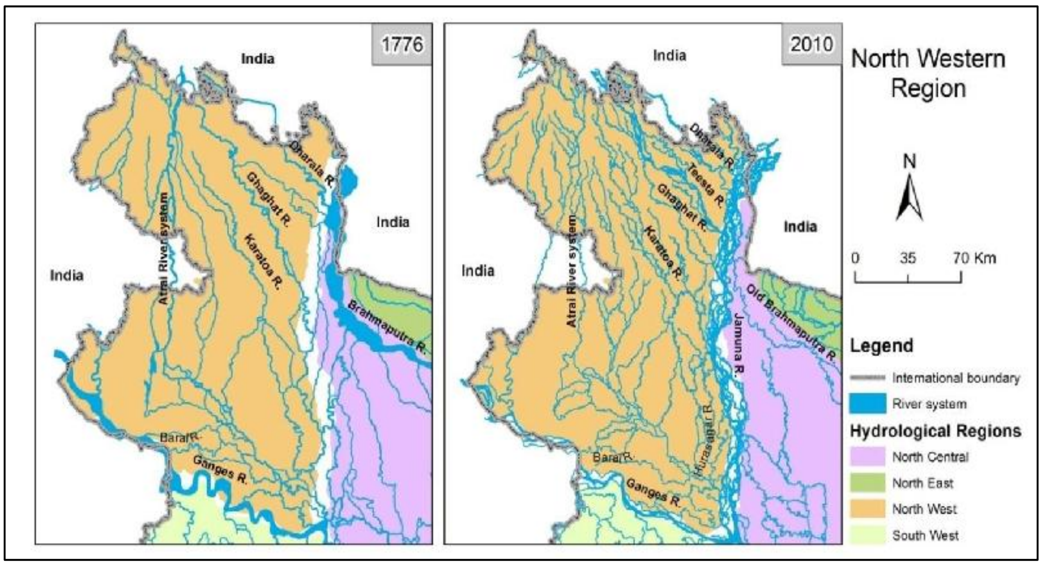

Figure 4.5: River system of North-West Region in 1776 and 2010

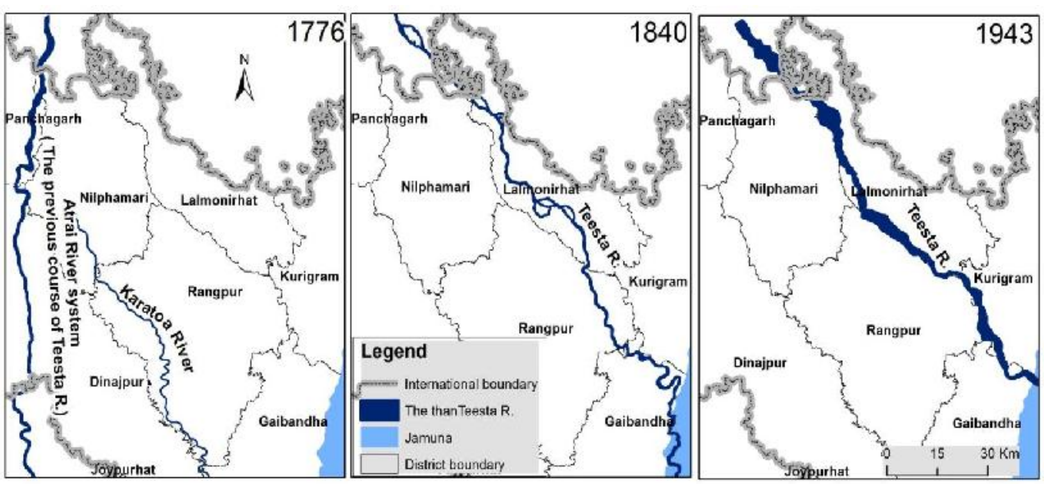

Figure 4.6: Historical changes of the Teesta River

The description of some major rivers of this region along with problems is given below.

TheTeesta

The Teesta is the largest fan river of the country which becomes flashy during the monsoon. The average width of the perennial river is about 3 km and the average length is around 113 km. Two barrages have been constructed on the river, one in India and the other in Nilphamari district of Bangladesh. In dry period Bangladesh does not get enough water because of the U/S water withdrawal.

As the Teesta is an alluvial fan river and has been elevating its levee, the river is now apparently shifting westward. There are many structures at the right bank of the river to resist the effect of regime change. An embankment provides covering for almost the entire right bank. The length of flood embankment is about 16 km and 48 km respectively along the left and the right banks.

The barrages do not permit enough water to flow through it during the dry season. As a result, water scarcity for irrigation recurs. Water level analysis indicates that more water is being stored in the dry season at the upstream of the Teesta barrage on the Indian side but during monsoon flood, the gate of the barrage remains open. In spite of many erosion protection structures along the river bank, erosion is a major problem for the floodplain dwellers of this dynamic river. Mainly coarse sand constitutes the sediments of this river. So, sand carpeting in this river due to flood is very harmful for the cultivation of land in the floodplain.

The Dharla

The Dharla River is a trans-boundary river in the north-west region of Bangladesh. It originates in the Himalayas where it is known as the Jaldhaka River. Average width of the whole river varies from 0.9 to 1 km over time with no significant trend of change. The length of the river within Bangladesh territory is about 55 km. The sinuosity is high in the downstream reach of the river. It receives flood discharge from the Indian hills in the upper reach and in the lower reach it receives discharge from Maldaha, Gidari and Ratnai Rivers. The river has about 49 km long flood embankment along the right bank.

Erosion occurs in many places during monsoon due to increasing of water flow. The upper reach of the river is less dynamic and erosion does not occur significantly. But in the lower reach, protection structures are needed to protect some kheya ghat and existing roads along riverside considering their importance.

The Atrai

The Korotoya-Atrai River originated in the Himalaya region of India. The river at first enters Bangladesh through Panchagarh District and retreats into India through Dinajpur District. Atrai re-enters Bangladesh at Dhamoirhat Upazilla under the Naogaon District. The river conveys huge amount of water during the monsoon period but the dry seasonal flow is very low.

Due to meandering nature of the river, erosion occurs in some places during the monsoon period and there are few important growth centers (Mohisbatan Hat- Mohadebpur Upazilla, Pathakata Hat- Manda Upazilla, Kashiabari-Atrai Upazilla) which need to be protected from erosion. BIWTA maintain a Class- IV navigation route through the river and it is difficult to maintain navigability during dry period. Year round navigation is possible only at the downstream part of this river.

The Dudhkumar

The Dudhkumar River is a trans-boundary river flowing in parallel with the Teesta and the Dharla River. It is known as Raidak or Sankos River in India. In Bangladesh, the river enters through the Bhurungamari Upazila of Kurigram

District. Though it is a large river, it is relatively steep on entry from India to Bangladesh. Among all trans-boundary rivers, the Dudhkumar is the sixth in length. The length of the river is about 65 km and the average width is about 460 m.

The river has become more sinuous and meandering in the last decades. The river bank erosion of the Dudhkumar River is significant particularly in Burungamari and Nageshwari. Bank erosion has been observed to occur at about 175 ha/year (1994 to 2010). Navigation is not possible in the dry season but in the monsoon it is only navigable in the lower portion of the river. More than 30 years ago, large cargo boats would carry jute and rice by the Dudhkumar River directly to Dhaka through the Jamuna River. But now-a-days small cargos carry goods to the Dudhkumar-Jamuna confluence due to lack of navigable depth.

The Baral Upper

This inter-district distributary river debouches from the Ganges at the Charghat Upazila under Rajshahi and drains into the Atrai River at the Gurudaspur Pouroshova under the Natore District. Inflow to the river is regulated through a regulator at Charghat. As such there is no flow during the dry season and the current is swiftest during August-September. There is no appreciable erosion anywhere. Local people raise low, temporary earthen dams across the riverbed and indulge in cultivation of paddy. Narod is its tributary and Musakhan is the only distributary.

The length of this river is 89 km (approx.) and the width varies from 27 m to 80 m. The river is meandering in nature. Slope of the river is 7 cm/km.There are several bridges, 15 regulators and 0.45 km bank revetment is present along the right-bank of the river.

It overflows its bank during seasonal flood. The regulator at Charghat does not work properly. The local people say that because of this regulator and other human interventions on the river, it is sedimented.

The Baral Lower

This district-level, close-circuit branch takes off the Atrai River at the Bhongoora Upazila, Pabna and returns to the parent river at the Faridpur Upazila, all under the district of Pabna. Though the upper reach dries up by March, water is available and as such boats ply throughout the year in the downstream reach. Monsoon flows overtopping both banks and erosion is observed at places during June-August. As such the river is widening but the flow is declining compared with the past.

The length of this river is 23 km (approx.) and the width is min 50 m, max 80 m and average 65 m. The shape of the river is meandering.

The river overflows the banks during seasonal flood. There are lots of human interventions such as roads, culverts, sluices etc. on the river. The culverts and sluices are not sufficient to pass the flow. People say that the conveyance capacity of this river is decreased for these interventions.

The Korotoya

The Korotoya River is a transboundary river. The river enters Bangladesh through Tetulia Upazila under Panchagar District and has out-fallen into the Atrai River at Dinajpur Sadar Upazila under Dinajpur District. Boats ply through the year round. The distributaries are the Goveshori, the Dhepa and the tributaries are the Ghoramara, the Choyai, the Satnai, the Talma, the Pathraj, and the Belan.

The length of this river is 187km (approx.) and the width is 55m to 293m where the shape of the river is meandering and the flooding slope is 31cm/km. There are bank revetments about 3.417 km and 2.335 km (respectively left bank and right-bank) and one groyene along the river.

The Karatoya is flashy in nature and flows through steeper terrain slopes. The monsoon brings about a drastic increase in flow and the river overflows of the banks. Erosion is also observed at some places. The river often dries up during dry season and the river bed is used for cultivation during the period.

The Hurasagar

The Hurasagor, a close-circuit branch of the Jamuna-Brahmaputra on the latter's right bank, issues from the Sirajganj Sadar Upazila under Sirajganj District. It reverts to the parent river at the Bera Upazila under Pabna District. The Bangali joins the river at the Shahzadpur Upazila under Sirajganj and the Atrai and the Gohalarivers join in the Bera Upazila under Pabna District. The combined flow continues downstream as Hurasagor and drains into the Jamuna-Brahmaputra.

Gohali, Ichamati (Pabna), Bangali and Atrai are the tributaries of the river. This river is seasonal. There is no flow of water during January-April. The flow of the river gradually increases during July-September. The river has no tidal effect.

The length of this river is 55km (approx.) and the width is 40m-90m where the shape of the river is meandering and the flooding slope is 4m/km.

There are several hat bazars, health centers along the river. There are Baghabari Highway Bridge and Baitara Sluice over the river.

During the dry season, flow declines in some upstream reaches of the river and at places it dries up as well. Paddy is cultivated at some places on the bed. When flow resumes during the rains, rising waters overflow her banks at places and during the time, erosion occurs at some other places. The river is silting up at present.

Summary

In general, erosion along the right bank of the Jamuna River has been affecting the life and resources of many people of this region. Moreover, erosion is a major problem for many other rivers of this region. Navigation and water scarcity for irrigation during the dry season are major issues mainly caused by upstream intervention beyond the border. This region is characterized by the tendency of high extraction of groundwater and diversion of river water for irrigation purpose. On the other hand, due to the flashy nature of the rivers and upstream intervention, flood is a common phenomenon for this region. Flooding was also identified as the main problem for this region in FAP 2 study.

Groundwater extraction occurs at high rate particularly, in the Barind Tract area. There may be an opportunity of diverting water into this area from Rajshahi irrigation project. This opportunity has to be evaluated in terms of social and economic issues.

Summary Table (North-West Region)	
Controlling features	• The Barind Tract • Atrai Basin • Chalan Beel

Summary Table (North-West Region)	
Major problems	• Transboundary rivers water sharing • Erosion • Navigation during dry season • Water scarcity for irrigation • high extraction of groundwater • Flooding • Human intervention

4.2. North-Central Region

4.2.1. Geographical Setting

The North- Central Region of Bangladesh covers the region bounded by the Jamuna, the Ganges, the Meghna and the Old Brahmaputra; it includes the national capital Dhaka. In the context of Bangladesh, this region and the regional rivers play an important role. The region is constituted by eight districts including Dhaka. There are about 60 rivers in the region. Among these, the Padma, the Old the Brahmaputra, the Shitalakhya, the Dhaleshwari, the Buriganga, the Kaliganga, the Bangshi, the Turag, and the Balu rivers are worth mentioning. The Modhupur Tract is situated in this region. Some of the rivers flow through the west and the others through the east of Madhupur (BWDB, 2011).

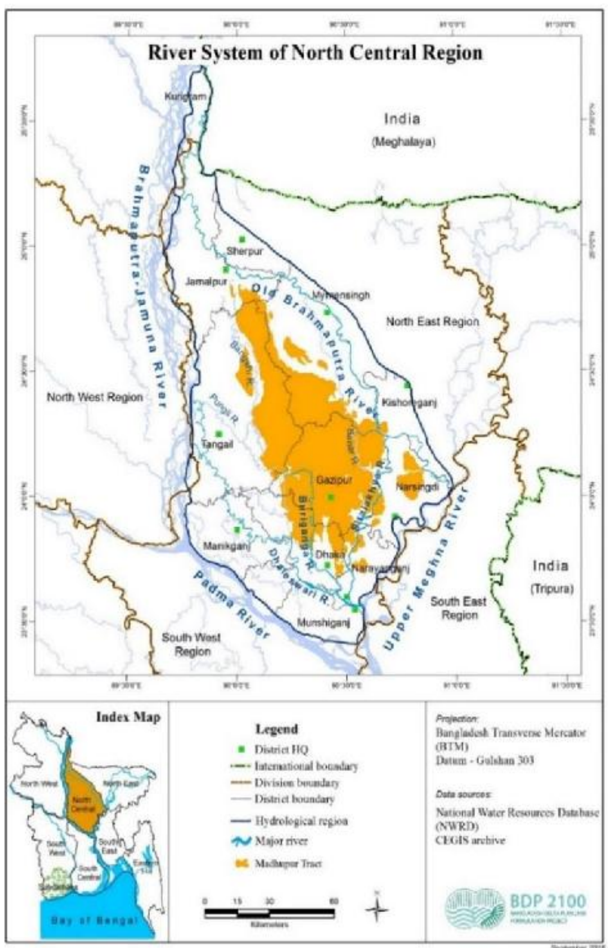

Figure 4.7: Rivers in the North-Central Region

4.2.2. Topographical Setting

The topographical slopes are roughly from Northwest to the Southeast. Some part of this region consists of a Quaternary Pleistocene Plateau, the Madhupur Tract, which lies higher above sea level than the surrounding floodplain. With the exception of the Madhupur Tract, this region is a semi-aquatic, deltaic environment regularly inundated by the Jamuna and the Old Brahmaputra. Flows in the major rivers in the region are mainly the result of spilling from left bank of Jamuna, which drains in a south-easterly direction to the confluence of the Ganges and the Meghna rivers. Consequently, the high stages in these two rivers impede the drainage of the region. The main spill-fed rivers in the region include the Old Brahmaputra, Jhenai, Dhaleswari, Kalignaga, Bangshi, Turag and Buriganga. Smaller, mainly rain fed rivers includes the Khiro, Banar and Lakhya.

The surface profile of NC-1 shows that the level of the Madhupur Tract is more than 16 m higher than that of the adjacent floodplains. Khiro, Sutia and Pagaria rivers are flowing in the Madhupur Tract (Figure 4.9). The Old Brahmaputra River is flowing on an elevation of 10 mPWD. The section NC-2 reveals that the Brahmaputra and Jamuna floodplain has higher land slope than that of the Ganges Floodplain. The Sitalakhya River is flowing 2 m higher land that the Balu River. There are identical land level of the Sitalakhya and Brahmaputra (Narshindi-Munshiganj) rivers. Young Brahmaputra and Jamuna Floodplain extend up to 50 km from the starting of NC-3 profile. Then the Madhupur Tract is about 40km along the profile with a peak level of about 20 mPWD. The land slope of the Young Brahmaputra and Jamuna Floodplain is about 10 cm/km. The distributaries of the Brahmaputra-Jamuna River, like Banar, Bangshi, Dhaleshwari and Kaliganga rivers, have developed their levees and those are reflected in the surface profile.

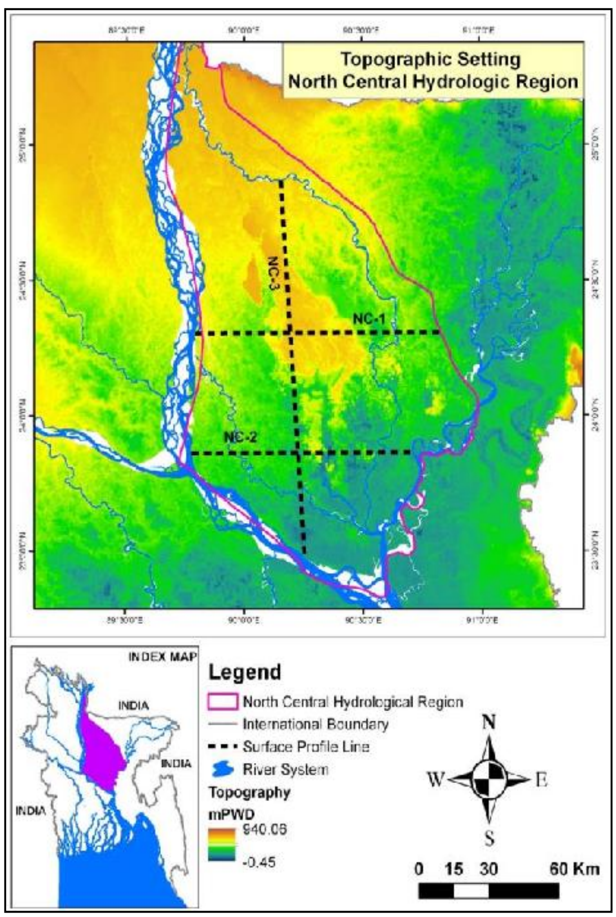

Figure 4.8: Topographical setting of North-Central Region

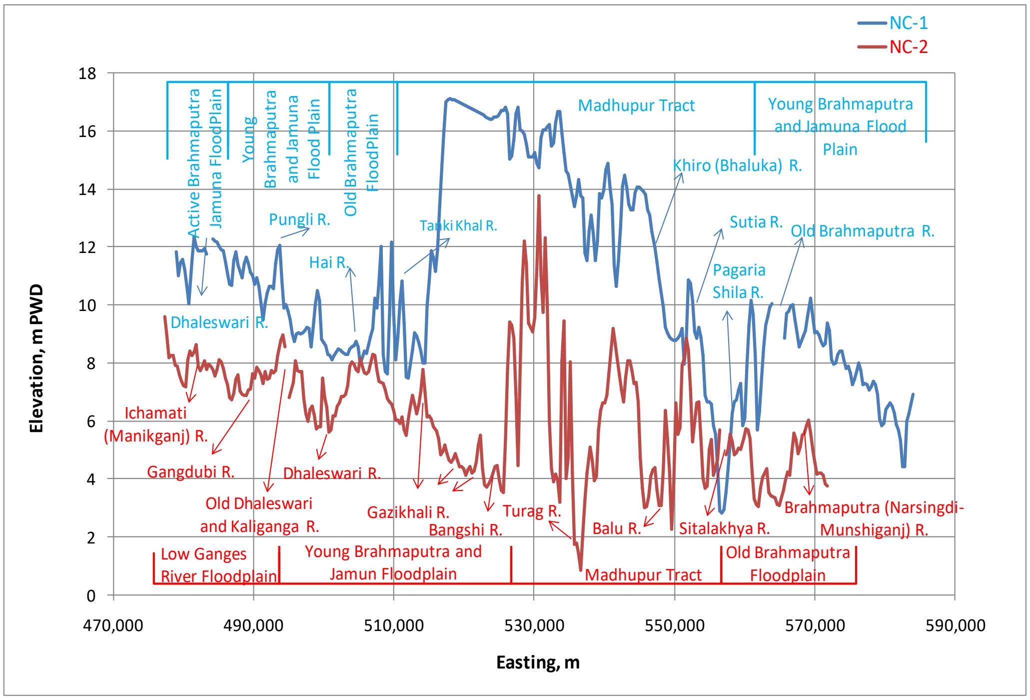

Figure 4.9: East west surface profiles in North-Central Region of Bangladesh

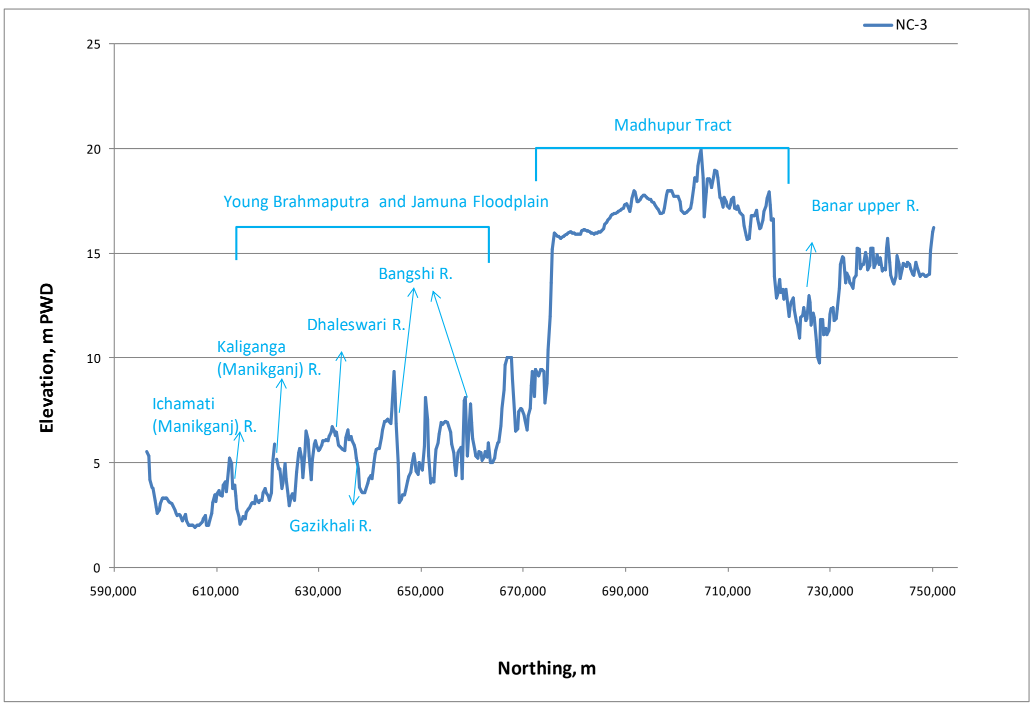

Figure 4.10: North south surface profiles in North-Central Region of Bangladesh

4.2.3. Historical Development and Problems

The region being gradually lower from northwest to south-east direction, most of the rivers take off from the Brahmaputra-Jamuna and the Old Brahmaputra and some drain into the Padma River and others into the Meghna River. The river system of this region was greatly influenced by the avulsion of the Brahmaputra River.

Figure 4.11 shows that the Brahmaputra River was flowing through the present course of Old Brahmaputra River along the northern boundary of this region. But since the avulsion of the Brahmaputra River, the rivers of this region have changed significantly. Enormous sediment supply from upstream through Jamuna and its avulsion attributed to the off-take sedimentation of major rivers of this region. As a result, reduced flow through these rivers has made them morphologically, inactive. Intensive industrial development has been occurring along the banks of many of the rivers of this region. For instance, various kinds of industries have been established along the banks of the Buriganga, Sitalakhya, Dhaleshwari, and the Turag rivers. Thus, water quality of these rivers has deteriorated and the reduced flow has aggravated the deterioration. Moreover, offtake-dynamics is an important feature for rivers like the Dhaleshwari and the Old Brahmaputra. The off-take dynamics is mainly caused by the instability in the Brahmaputra-Jamuna River.

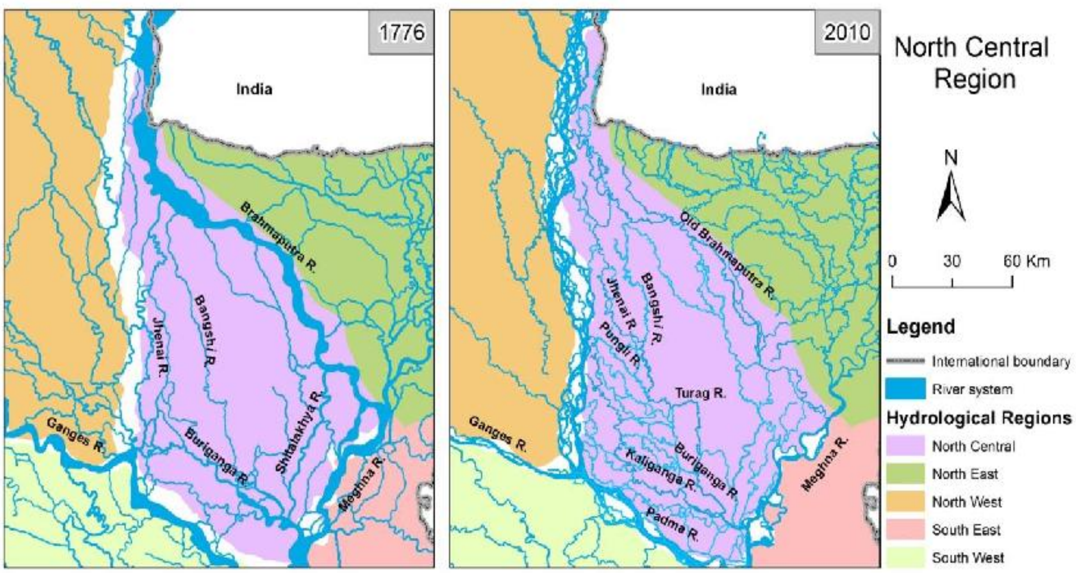

Figure 4.11: Evolution of river system of North-Central Region

The descriptions of some major rivers of this region along with issues are given below.

The Old Brahmaputra

The Old Brahmaputra River is one of the main sources of water for the north-central region. The river has been degradingsince the avulsion of the Brahmaputra River through the Jamuna about 200 years ago. Presently, the Old Brahmaputra River is a degradingdistributary of the Brahmaputra-Jamuna River and flows over the old bed of the Brahmaputra River. The length of the river is about 283 km.The off-take of the river is the most dynamic and uncertain part of the river. The location of the off-take is not well defined or there is more than one off-take of the river (**Figure 4.12**).

The drastic decrease of dry season discharge makes navigation increasingly very difficult and the route has long been abandoned by vessels. The erosion rate along the river shows a decreasing trend but there are some places in Jamalpur and Mymensingh districts where important growth centers are needed to be protected.

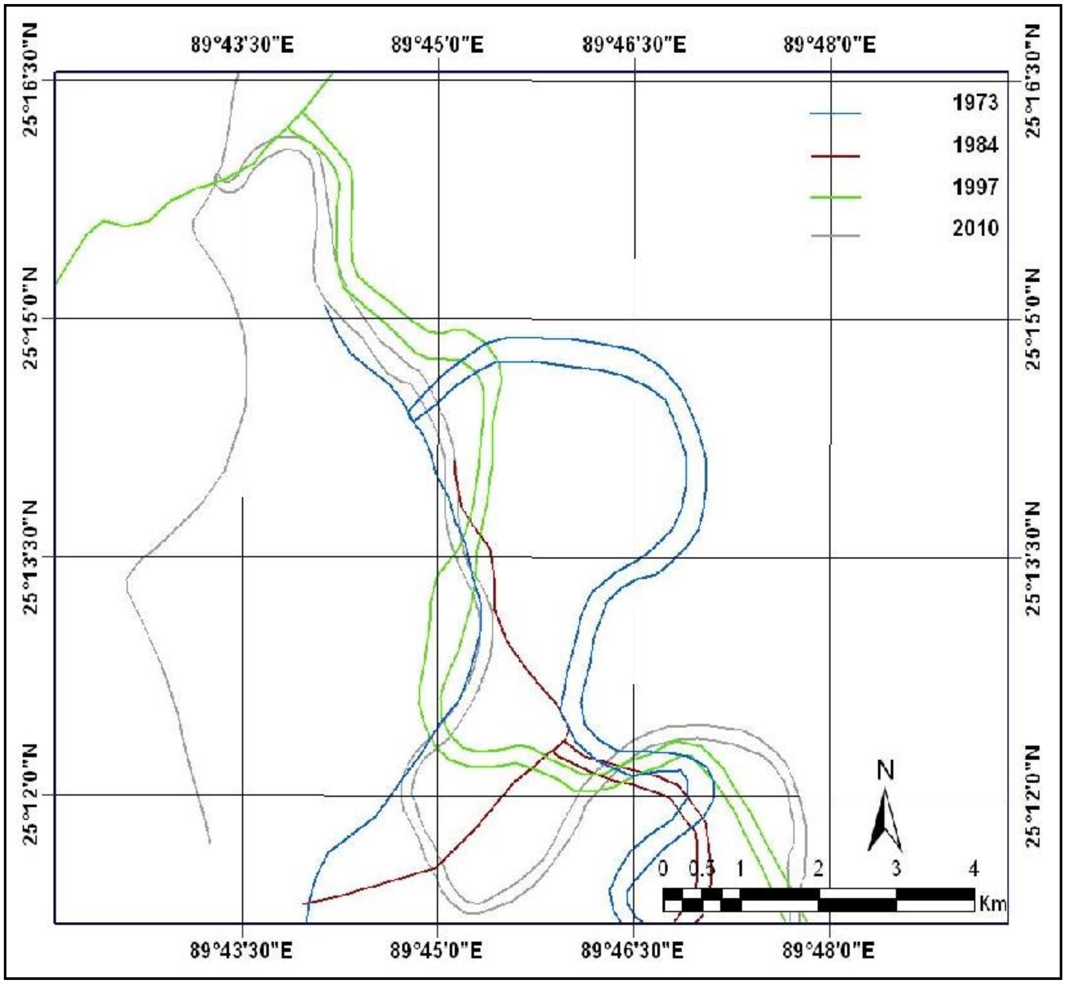

Figure 4.12: Location of the off-take of the Old Brahmaputra River (CEGIS 2010)

The Shitalakhya

The Shitalakhya River is a distributary river of the Old Brahmaputra River which receives fresh water flow from the Old Brahmaputra and the Banar Lower rivers. Due to the abandonment of the original link to the Old Brahmaputra River, it receives most of its freshwater flow presently through the Lower Banar River. The relatively inert geo-morphological characteristics of the river make available fairly suitable water depths for navigation throughout the year. Many industries have developed along both sides of the river. Thus, this river has an important role in the economy of Bangladesh. The bank materials of the relatively inert river are erosion-resistant and the flow is not sufficient to induce meandering bend migration. This is an underfit river which is probably unable to adjust its channel geometry with the reduced discharge due to lack of sediment supply from the upstream. Being a less dynamic river, it has facilitated the growth of industries, commercial centers and power plants on either of its banks. The river is about 108 km long and the average width is 230 m.

Water quality is a matter of concern as the river water is maintaining lower DO and BOD levels. In order to maintain good water quality and healthy environment, chemical and dying industries should be restricted along both sides of the river. Moreover, it is important to protect the river from encroachment and from discharging industrial effluent without treatment.

The Dhaleshwari

The Dhaleshwari River is a left bank distributary of the Jamuna River. Presently, the river has become a mere flood spill channel due to vulnerability of its off-take to sedimentation and thus, has also has become a low-energy river. Its off-take has changed significantly during 1973 to 2010 (**Figure 4.13**). During 1960s, about 8-9% of the Jamuna flow volume was diverted through the Dhaleshwari River which has reduced to less than 1% during the late 2000s. In response to decreased discharge, the width of the river has been reduced from 1200 m to 300 m since the early-1940s. The river has no significant erosion-accretion process and accretion is the prevailing process in some reaches. The length and average width of the river is about 292 km and 144 m respectively.

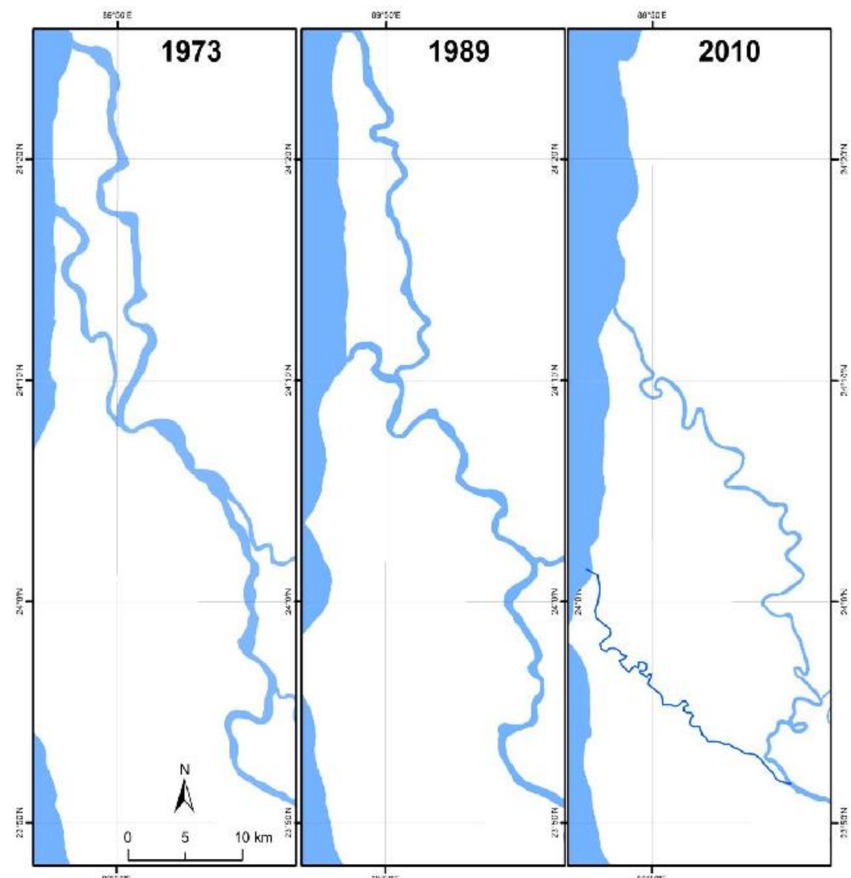

Figure 4.13: Shifting of the location of the south (present) off-take of the Dhaleshwari River (CEGIS 2010)

Presently, channel abandonment occurs due to reduced flow regime and human encroachment. Navigation facility is not available in the upstream part due to off-take sedimentation.

The Buriganga

The Buriganga River is located in the southeastern part of the north central region of Bangladesh. Dhaka city is situated on both the banks of the Buriganga River. At present, the Buriganga has become downstream contribution of the Turag River and a tributary of the Dhaleswari River. The river is about 29 km long and its width varies from 80 m to about 480 m. The river has immense contribution to the economy of Dhaka city though the industries along the river banks are continuously polluting the river. It provides waterway navigation through launch and country boats throughout the year. Its course in Dhaka is stable, fixed by the resistant clays marking the southern edge of the Madhupur tract. The bankline of the river has been found to remain almost fixed for the last 60 years except changing of the off-take.

The Buriganga is an underfit river which carries the most polluted water among all the rivers of Bangladesh. The flow of the river has been reduced significantly due to sedimentation in the off-take. The discharged waste materials from industries and reduced flow have deteriorated the water quality significantly.

The Bangshi

The Bangshi River was the distributary of the Old Brahmaputra located at Jamalpur. That offtake was closed in the early 1970's and now the Bangshi only drains the water from the Madhupur Tract. The area acts as a flood water storage area. There is potential for improving flow out of this area by increasing the capacity of the Old Bangshi through Regional Scheme. The majority flow of the Bangshi flows into the Turag River to the east with smaller flows into the Old Bangshi. Waste water as well as waste materials from nearby industries are disposed into this river. As a result, the river is seriously polluted.

The Pungli

The length of this river is 39km (approx.) and the width is 112m to 153m where the shape of the river is meandering.

There are three highway bridges and one railway bridge on the river.There are bank protection works about 3 km and 20 km (left-bank and right bank respectively), 1.943km bank revetments (left bank and right bank) and two spurs (into 31 km to 31.20 km) along the river.

The Jhenai

The river originates from Old Brahmaputra River in Melandaha Upazilaabout 10km to the northwest of Jamalpur District. Named as Fatikjani and Chapai, the river falls into the Bangshi River in Kalihati Upazila at Tangail District. No flow is available in the river during January-March. Jharkata River has merged into the Jhinai River and again has flow out at Sarishabari Upazila under the district of Jamalpur. Chatal is the tributary, Jharkata, Chapai are the distributaries and Bairan is the branch of the river.

The length of this river is 133km (approx.) and the width is 35 to 107m where the shape of the river is meandering and the flooding slope is 7cm/km.

There is a regulator of six vents at Kabaribari Upazila on the river. There are river bank protection about 10.868 km and 4.020 km (left-bank - Jhepana - Kariyataephasidiai project, right-bank part - scatter – Laxmibacha ghatail sub - projects) along the river.

The river overflows its banks in some places during monsoon. The flow has decreased related to the past as the mouth of the river is silting up. This phenomenon is also causing degradation of the river bed.

Summary

In general, maintaining navigation facilities is a major problem for this region as many rivers have become morphologically inactive. Discharged effluence and waste materials from industries have caused deterioration of water quality significantly and human encroachment is occurring intensively along the banks of the rivers. In FAP 3 Study, the main focus was flood and drainage control and priority was given to maintain controlled flooding through gated structure in this region.

Summary Table (North-Central Region)	
Controlling features	• High level of the Madhupur Tract
Major problems	• Maintaining navigation facilities • Deterioration of water quality • Human encroachment along the banks of the rivers

4.3. North-East Region

4.3.1. Geographical Setting

The North-East Region is bounded by the Indo-Bangladesh border and the old Brahmaputra River at south and west covering an area of about 20,000 km^2, about half of which lies below 8 m above sea level (Figure 4.14). A tectonically active basin is situated at its central part which is subsiding. Presently, this region is covered by 87 rivers, including, 20 trans-boundary rivers. The Barak from India bifurcates at Amalshid into the Surma flowing due west and the Kushiyara flowing due southwest (BWDB, 2011). The Moharoshi, Chitakhali, Dudhda, Bhogai, Kongsha, Ghagtiya, Sagorkhali, Nitai rivers enter Bangladesh and drain into the Baulai as the Bhogai –Kongsha. The Someswari flows in different courses under different names near Durgapur. At present, one of the three branches of the river drains into the Bhogai, the second into the Ubadakhali and another as the Atrakhali into the Ubdakhali. In addition, the border rivers Jadukata, Jhalukhali, Umiam, Piyain, and Sari Gowain debouch from the northern hills and outfall into the Surma River.

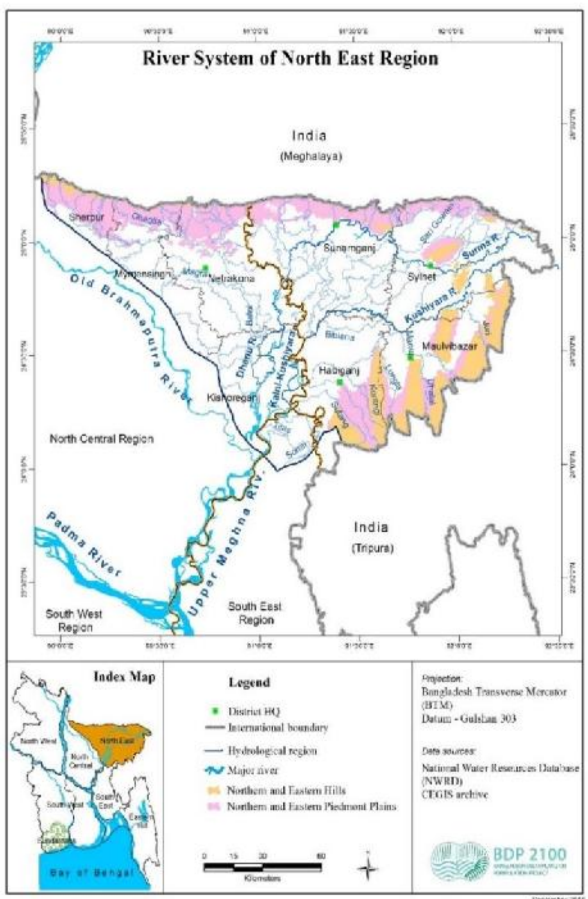

Figure 4.14: Rivers in the North-East Region

4.3.2. Topographical Setting

The Sylhet Basin contains numerous large, semi-natural wetlands like haors, baors, and water falls. This basin is close to Cherapungi in India which generates the highest rainfall in the world. The basin drains through an outlet at south. The base level of this outlet, however, is governed by the monsoon flow of the Brahmaputra-Ganges, one of the largest river systems in the world. The range of mean annual rainfall in the Mehgalaya, Barak and Tripura systems are 3,200-8,000mm, 1,600-4,000mm and 2,000-4,200 mm, respectively (FAP 6). This enormous amount of water from these rainfalls, along with water caused by the local rainfall (3,670 mm in the northeast region), drains out through this northeast region. Heavy rainfall during early monsoon in the Meghalaya Hills causes the flash flood in the haor area and frequently damages the boro crop. This crop is the only crop in the haor areas.

The Section of NE-1 exhibits that the Baulai River is flowing at a land level of 2 mPWD. The Dhala, Soai, Mogra and Dhalai-Bishnai rivers are flowing in the Old Barhmaputra floodplain with a slope of 15cm/km. The Bhogai-Kangsho River has leveled up few parts of the land slope. The Old Surma River is flowing 5.5 m above than the land level of the Bauli River. The section of NE-2 shows similar land slope until it reaches upto the Dhanu River. In the Section from 595 to 605 km easting, the land of NE-1 is about 4 m above than that of NE-2.

Figure 4.17 shows the north-south directed surface profile of Section NE-3. The trend of land levels in Bangladesh is sloping from north to south, but different characteristics are observed in North-East region. The surface profile shows that the land slopes in the Sylhet Basin are in reverse direction. This phenomenon is well supported to the higher subsidence rate in the northern part of the basin.

The bottom of the Sylhet Basin is elongated in the north-south direction, with a deeper bottom and very steep slopes at the northern edge. The slopes of both east and west edges are milder and vary from 15 to 30 cm/km with a flat bottom several kilometers wide. The rivers entering into the basin from the east and the west and flowing over the side slopes in the east-west direction, turn towards the south while they flow over the flat bottom of the basin.

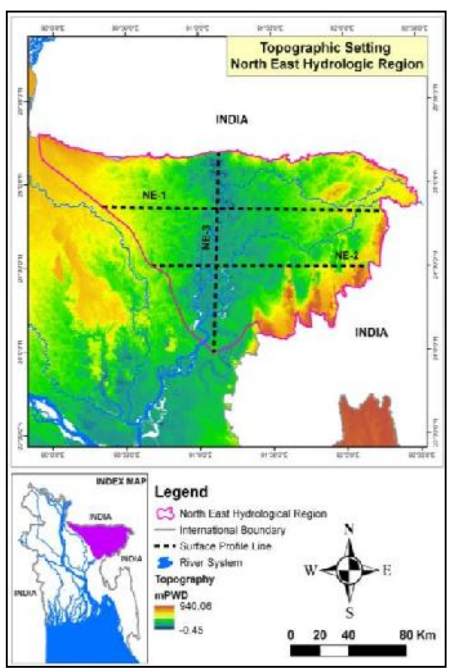

Figure 4.15: Topographical setting of North-East Region

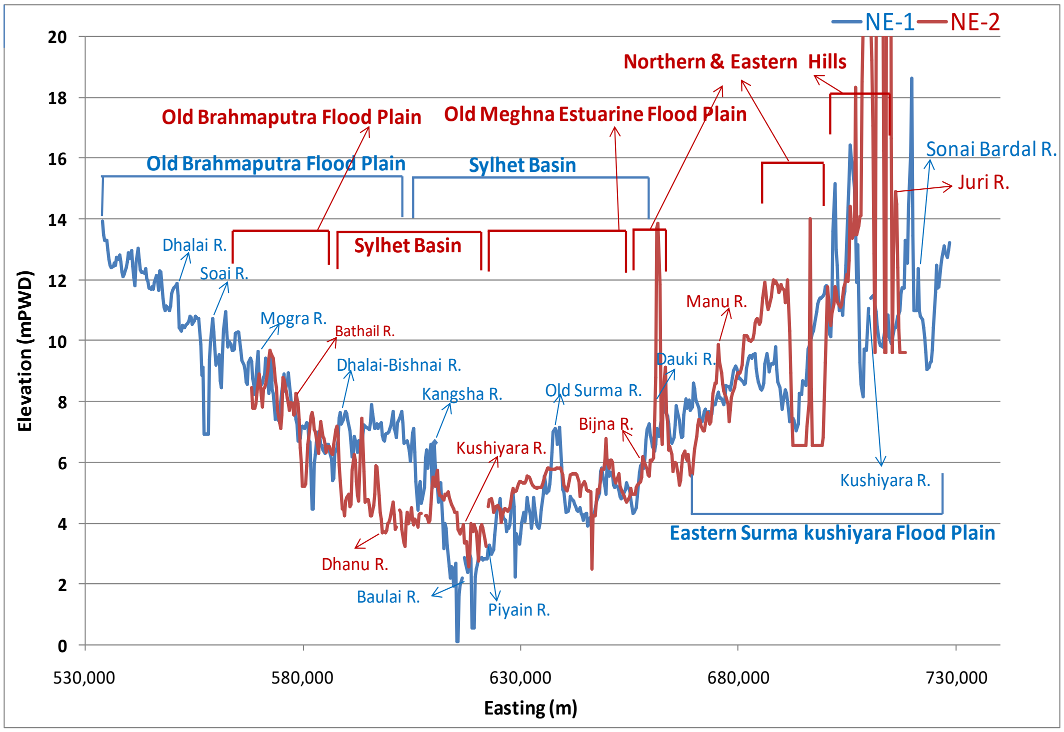

Figure 4.16: East west surface profiles in North-East Region of Bangladesh

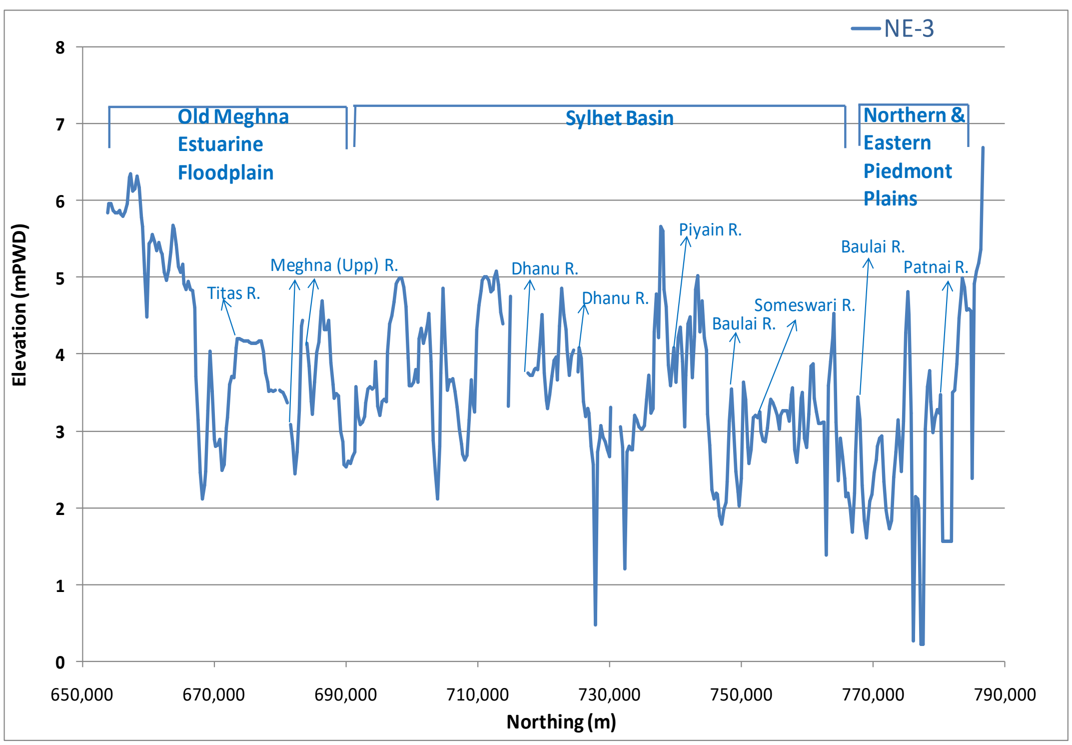

Figure 4.17: North south surface profiles in North-East Region of Bangladesh

4.3.3. Historical Development and Problems

The physical process of this region is substantially different from other regions of the country. Subsidence of the Sylhet Basin is the most prominent feature for the river system of this region as this region is experiencing higher rate of subsidence than nominal subsidence rate of deltas. Subsidence can cause avulsion of rivers, changes in their planform pattern and increase or decrease of sinuosity. In this region, the courses of the rivers Surma, Kushiyara, Someswari and Kangsha have been avulsed towards the north which indicates the influence of subsidence, the rate of subsidence is maximum in this direction. This increased subsidence rate is mainly caused by the sediment starvation due to the avulsion of the Brahmaputra River. When the Brahmaputra was flowing along east of the Modhupur tract, the rivers in this region were hydro-morphologically active. Huge amounts of water and sediment have being carried through the Brahmaputra to this region. There was thus, a balance between siltation and subsidence in this region. Following the diversion of the main flow of the Brahmaputra to the west of Modhupur nearly 200 years ago, there occurred a sediment starvation in this region. Subsidence became the dominant process and as a result, the elevation of land started declining. The northern part of the region being most depressed, the rivers showed a tendency of shifting towards the north. In addition, the Sylhet Basin being tectonically active, it accelerated the changes in these rivers.

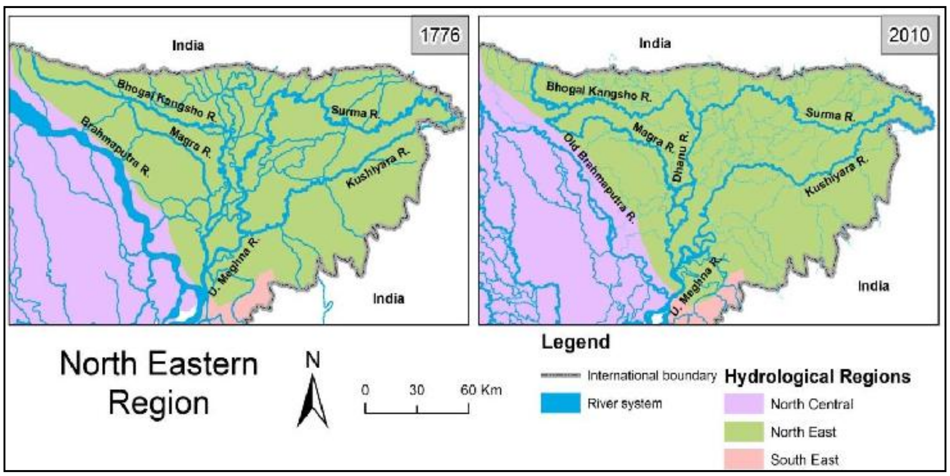

Figure 4.18: Evolution of river system of North-East Region

The description of some major rivers of this region along with problems is given in the next section.

The Surma

The Surma is a trans-boundary river which has originated from the Barak river of India. The average width of the river is about 110 m. The length of the river is about 250 km. The depth and width of this perennial river are increasing day by day. Course shifting and avulsion are common phenomena at downstream reaches of the river. The process of active sedimentation attributes to the channel abandonment and development process of the Surma River. The course of the river has shifted towards the north where the rate of subsidence is at its maximum. The upstream and downstream parts of the river are defined as Class-IV and Class-II navigation route, respectively by BIWTA. It should be mentioned that sand, gravels and bolders from Sylhet are transported to different parts of the country through this river.

Surma River is susceptible to erosion at the downstream reach situated in the Sylhet Basin. Navigation facility is hampered due to the active sedimentation process in the river. Available depth for navigation is less in the Sylhet Basin, especially in a certain reach from where the elevation difference between the monsoon flood and river bank level starts to increase.

The Kushiyara

Trans-boundary river, the Kushiyara, has entered Bangladesh at Jakiganj Upazilla after originating from the Barak River in India. The total length of the Kushiyara is 289 km. After meeting with the Mora Surma River at Markuli, the river flows as the Kalni-Kushiyara River and when it meets with the Surma-Baulai, the combined flow is named as the Meghna. A major part of the Kushiyara River lies within the deeply flooded Sylhet Basin and a tendency of northward shifting is observed for this part. Cut-offs and avulsions are frequent within Sylhet Basin part of the river. The river is defined as Class- III route for navigation by BIWTA. It should be mentioned that this river is a part of Bangladesh-India Protocol navigation route.

Within the Sylhet basin, the bank erosion rates are high and channel cut-offs are also frequent. Navigation depth of the river has decreased in the part of the river along Sylhet Basin.

The Dhanu

The Dhanu River is located in the Sylhet Basin which is tectonically very active. Flood is a common phenomenon of this river as the perennial flow increases manifold during the monsoon and inundates the surroundings. The river is about 90 km long and its width is around 228 m. Inundation depth of the Dhanu River floodplain ranges from a meter to a couple of meters. The river is an important navigational route classified by the BIWTA as it provides sufficient depth for navigation throughout the year. The diversion of the Kushiyara river flow caused the water level to rise in the Dhanu River, which may have triggered the development of a new channel from this river downstream of Itna to further west to the Ghora Utra River.

Building settlement platforms is a problem in the surroundings because of the high inundation level. Bank erosion is a common problem here, as there are some settlements and important infrastructures on the banks of this river.

The Kongsho

This trans-boundary river has entered Bangladesh as Bhogai through the Nolitabarhi Upazila under the Sherpur District. It bifurcates into the Ichamoti and the Kongsho at Morichapura Union and reunites at Phulpur Upazila, Mymensingh, retaining the latter name. At present, the main flow is diverted through the former channel. It assumes the name Khowai at the Bowshi of Barhat-ta, Netrokona and outfalls into the Baolai River at the triangle of the Dhormopasha, Jamalganj and Mohonganjupazilas. This is a Class-IV Route of the BIWTA.

The length of this river is 228km (approx.) and the width is 45m to 131m where the shape of the river is spiral. The river consists of 115.76km flood embankment at right bank of the river. There are one of Bridge and 12 nos. of regulator in the river. There is 0.8km and 0.45km bank revetment accordingly along the right and left bank of the river.

As the flow of this river is perennial, there is flow of water throughout the year although the flow of the river increases during July-September and moderately decreases during dry season (February-April). The river does not have any tidal effect throughout the year. There is erosion in the river, so that the riverbed is rising day by day. With a significant loss in conveyance, the river cannot accommodate the water during monsoon and overflows its banks towards the floodplains.

Summary

Inadequate sediment supply from upstream causes acceleration of subsidence rate in this region. On the other hand, increased sediment supply from the upstream, beyond the international border, intensifies avulsion and abandonment of the river courses, river erosion, sedimentation, decrease in navigational depth and early floods within the Sylhet Basin. Alluvial fan rivers at the northern part of the region cause sudden channel shifting very irregularly and resulting into abandonment of existing channels and creation of new channels across the fan area. Channel erosion during the formation of new channel and channel spill on newly formed rivers are the main hazards for the local people. After an avulsion, new channel starts to accommodate high velocity from the spills, and as the bed and bank materials are very loose, lands adjacent to new channel are very vulnerable to erosion. The boundary of these fans ends in the haor and increase of fan areas results into the encroaching of the deeper part of haor which is one of the main causes of deterioration of haor eco-system, especially in the haors at Meghalaya foot-hills. The fan forming rivers often spread sand in the haor margin or at the Kanda of the haors which also cause to damage the crops and reduce the productivity of the land. Thus proper sediment management is significant for this region to compensate the subsidence and other effects of climate change as well as to maintain the ecosystem.

Summary Table (North-East Region)	
Controlling features	• Subsidence • Tectonically active Sylhet Basin • Tendancy of the rivers to shift towards north
Major problems	• Acceleration of subsidence rate • Pre-monsoon flash flood • Channel erosion during the formation of new channel • Damage of crops through sand spreading by fan rivers

4.4. South-West and South-Central regions

4.4.1. Geographical Setting

This region is bounded by the Ganges and the Padma in the north, the Bay of Bengal in the south and Lower Meghna River to the east (**Figure 4.16**). At present, 99 rivers, including 5 trans-boundaryones, are flowing through this region. More than half of the region is influenced by the tide, and salinity intrusion is a common feature for several kilometers inland from the Bay of Bengal (BWDB, 2011).

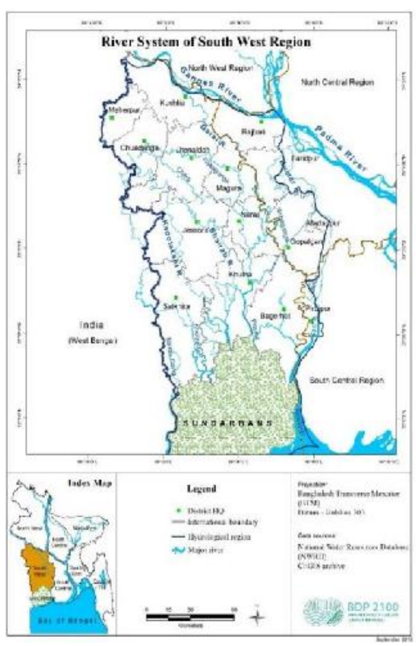

Figure 4.19: Rivers in the South-West and South-Central regions of Bangladesh

4.4.2. Topographical Setting

Based on elevation, the southwestern part of the delta can be characterized by three distinct features. The elevated area at the northwestern tip has a higher gradient and mainly consists of the Ganges floodplain, as shown in profile of section SW-1. Next to this unit, there is a southwest to northeast aligned stretch of low lying area having minimum elevation below MSL, which is classified as the Gopalganj-Khulna Beels, located in between Haparkhali and Nunda Utra rivers in section SW-2. This depression is dissected by recent and old courses of the rivers, like the Bhairab, Atai, Atharbanki, Madhumati rivers. The southern most section SW-2 shows that the slope found from 390 to 440 km easting is about 9 cm/km, whereas, there is a reverse slope with less than 2 cm/km in the rest of the section as a contribution of the delta building process through the Meghna estuary.

Two north- south directed profiles of section SW-3 and SW-4 exhibit that the topography of the southwest region is characterized by a very gentle slope and a large part of the delta lies 2m below the PWD datum, which is equivalent to about 1.5 m above Mean Sea Level (MSL). The areas along the coast consist of the Ganges tidal plain at a higher elevation than the Gopalganj-Khulna beels. The terrain has a reverse slope to the south, as found in section SW-4. The southern part of section SW-3 (not shown in the analysis and results) is the Sundarbans.

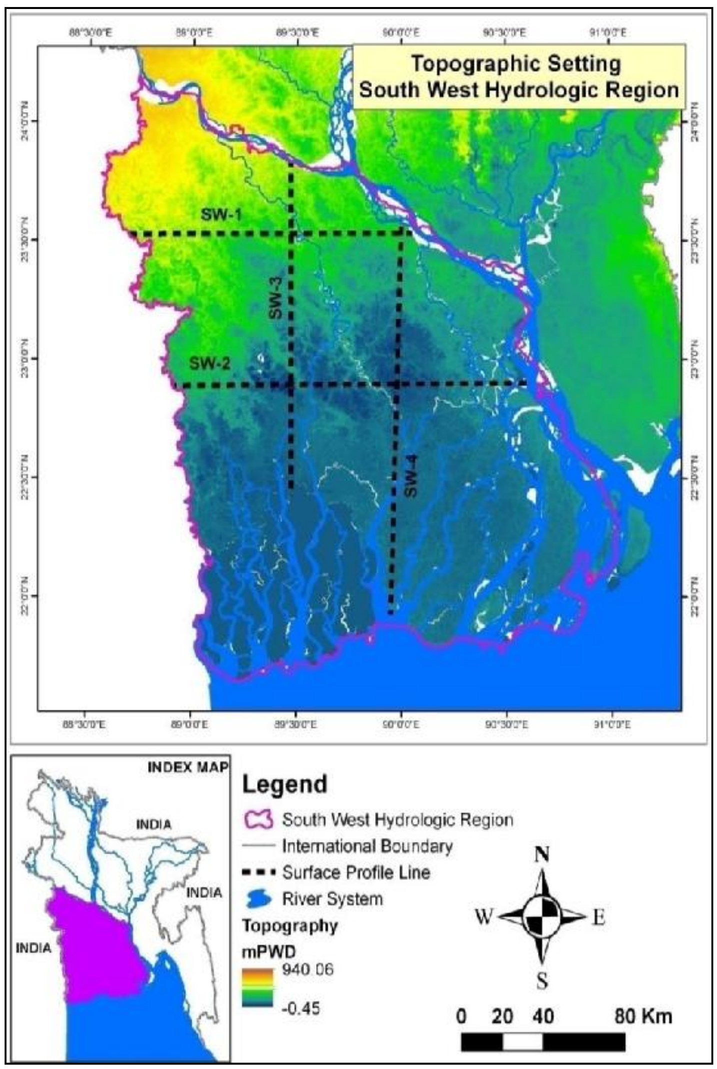

Figure 4.20: Topographical setting of the South-West and South-Central regions of Bangladesh

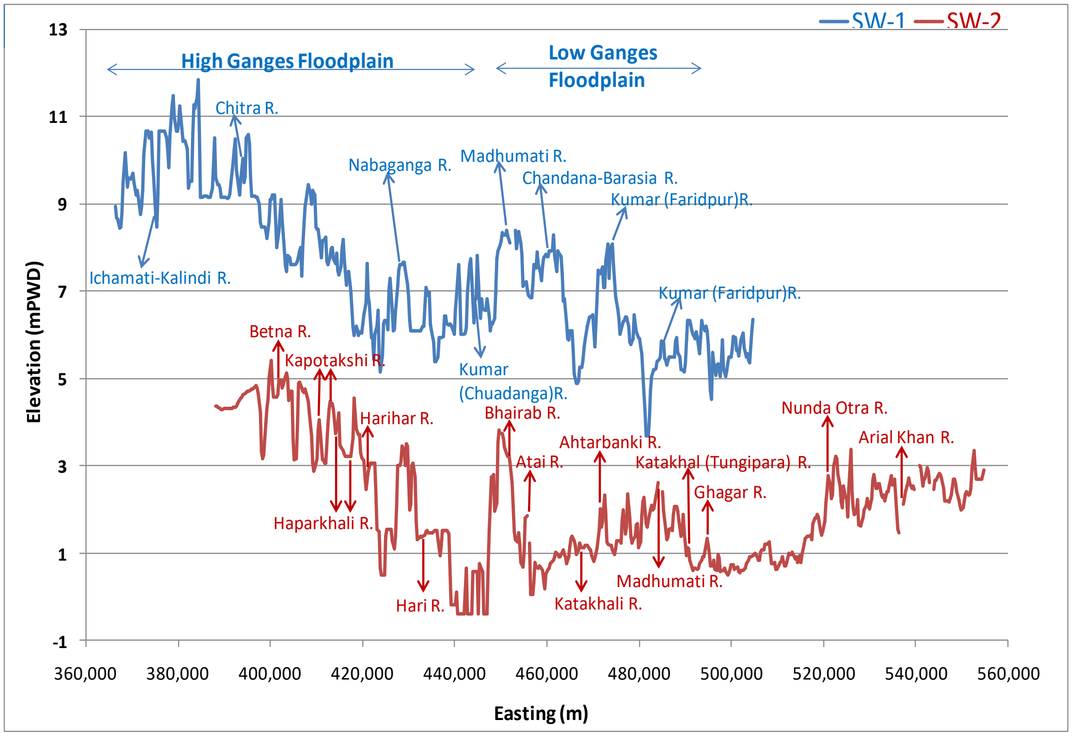

Figure 4.21: East-west surface profile in South-West and South-Central regions of Bangladesh

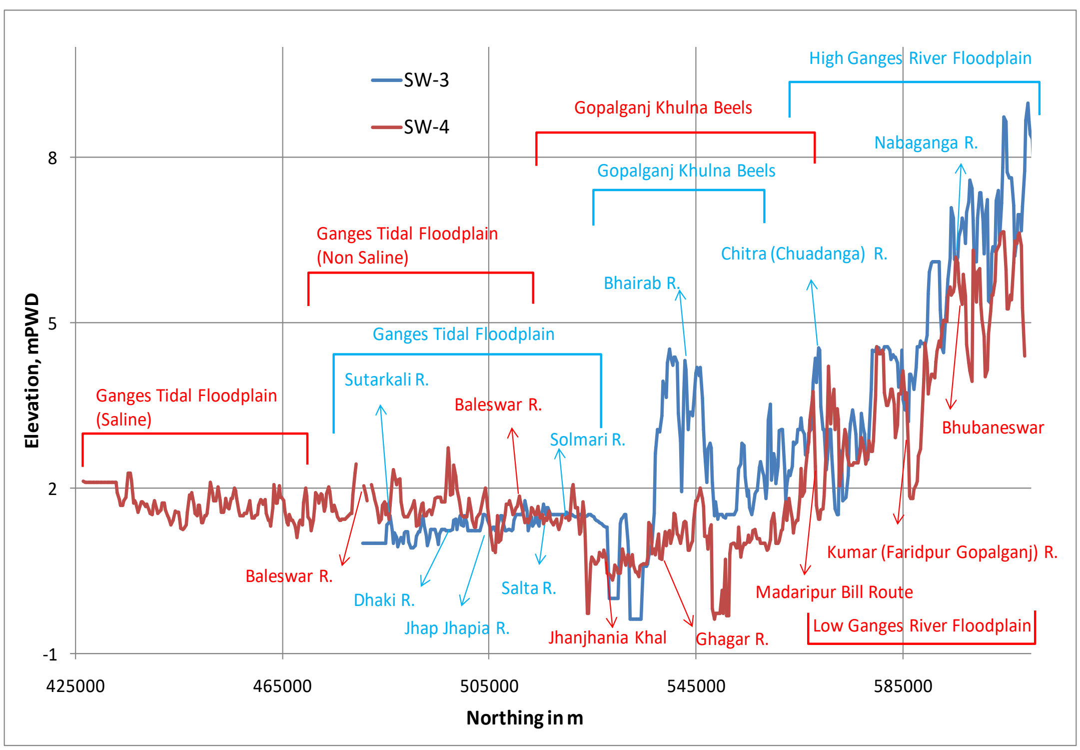

Figure 4.22: North -south surface profiles in South-West and South-Central regions of Bangladesh

4.4.3. Historical Development and Problems

The region is a complex of inter-linked ecosystems in the delta of the Ganges-Brahmaputra Rivers. Delta progradation or delta building process is the most eminent feature of this region which is influenced by tectonic and seismic activities. The sediment generated by 1950 Assam earthquake is considered to have immense effect on this delta building process, especially on the topography of the estuary (Brammer, 2004). Moreover, erosion of the Himalayas, highland boundaries, avulsion of Brahmaputra has influenced the process. This active delta building process has impact on accelerating the dynamics of rivers and Meghna estuary of this region (Sarker M. A., 2013). The overall river system of this region was flowing eastward previously. But the rivers are now flowing westward due to the adjustment with the delta building process (Figure 4.23).

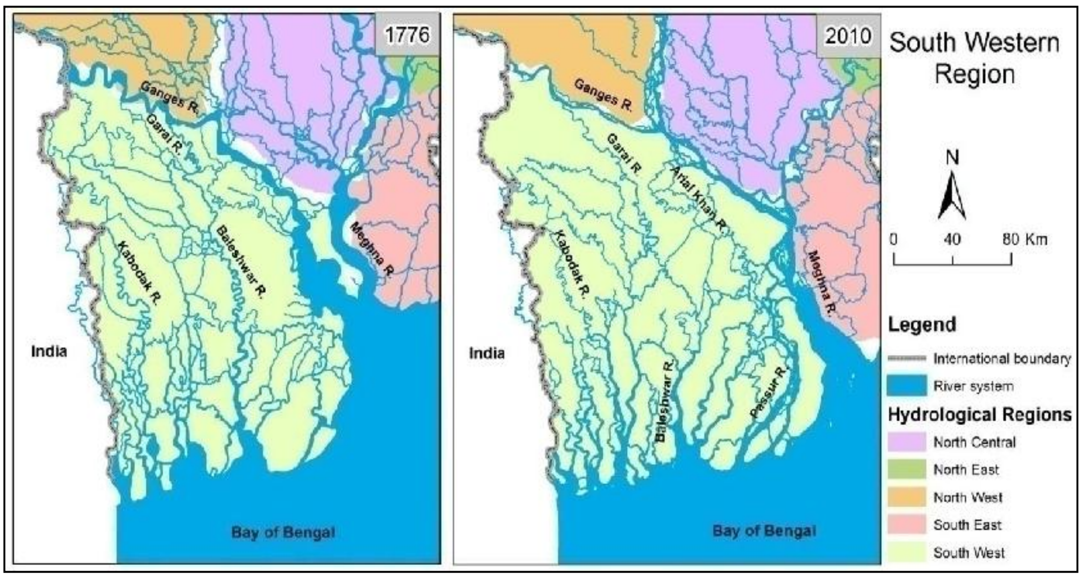

Figure 4.23: Historical evolution of rivers in South-West and South-Central regions

Following the avulsion of the Brahmaputra River and its joining with the Ganges, significant changes occurred in the river system of this region. It is believed that the combined flow of the Ganges and the Jamuna had raised the water level. In the early 20th century, the Gorai and the Arial Khan rivers, as the distributaries of the Ganges and the Padma, had turned into pretty large rivers. These rivers are the most important rivers for this region as they are the main sources of fresh water flow which eventually reduces the salinity. But due to Farakka Barrage operation, reduction of time for retarded scour and erosion at upstream of Gorai off-take, the condition of the Gorai River has deteriorated day by day (Figure 4.24). Another major change of this region is the evolution of the Arial Khan River. Nearly 240 years ago (according to Rennel's map of 1776), the Ganges River flowed along the present course of the Arial Khan River to the Bay of Bengal on the west side of Bhola district. Avulsion of the Brahmaputra River to the Jamuna River caused increase in flow of the Jamuna and Ganges rivers. A small channel, the Kirtinasha River was created from the Ganges to the Meghna River and the main flow of the Ganges Riveras diverted through the Kirtinasha River to the Meghna River. Subsequently, the Arial Khan, the old course of the Ganges River, became the right bank distributary of the Padma River (Figure 4.25). As many as five mouths of the Arial Khan River can be identified at the early of the 20th century (Figure 4.26). At present excepting the main course, others have nearly dried up.

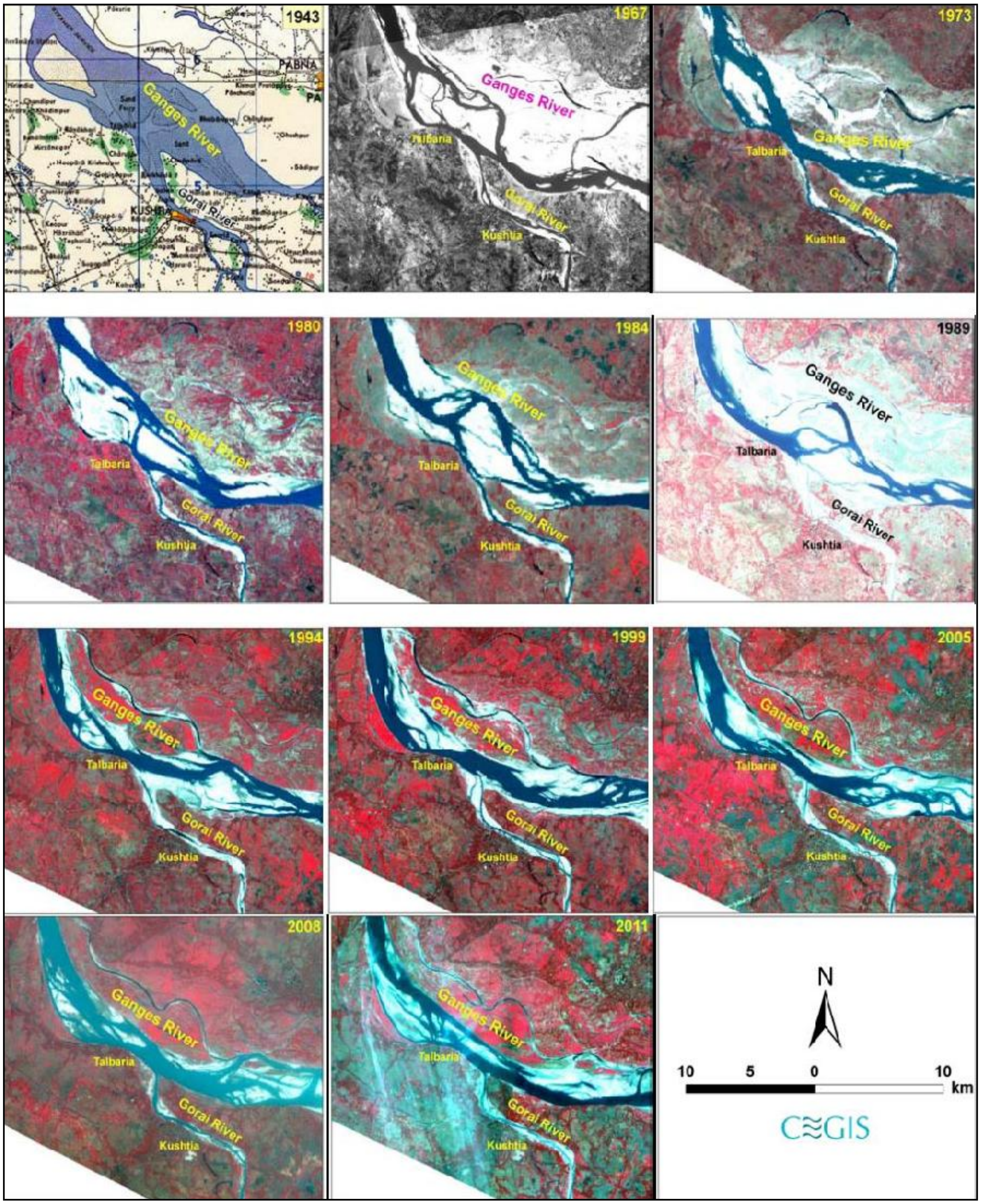

Figure 4.24: Images showing planform changes at the Gorai off-take area (CEGIS, 2011)

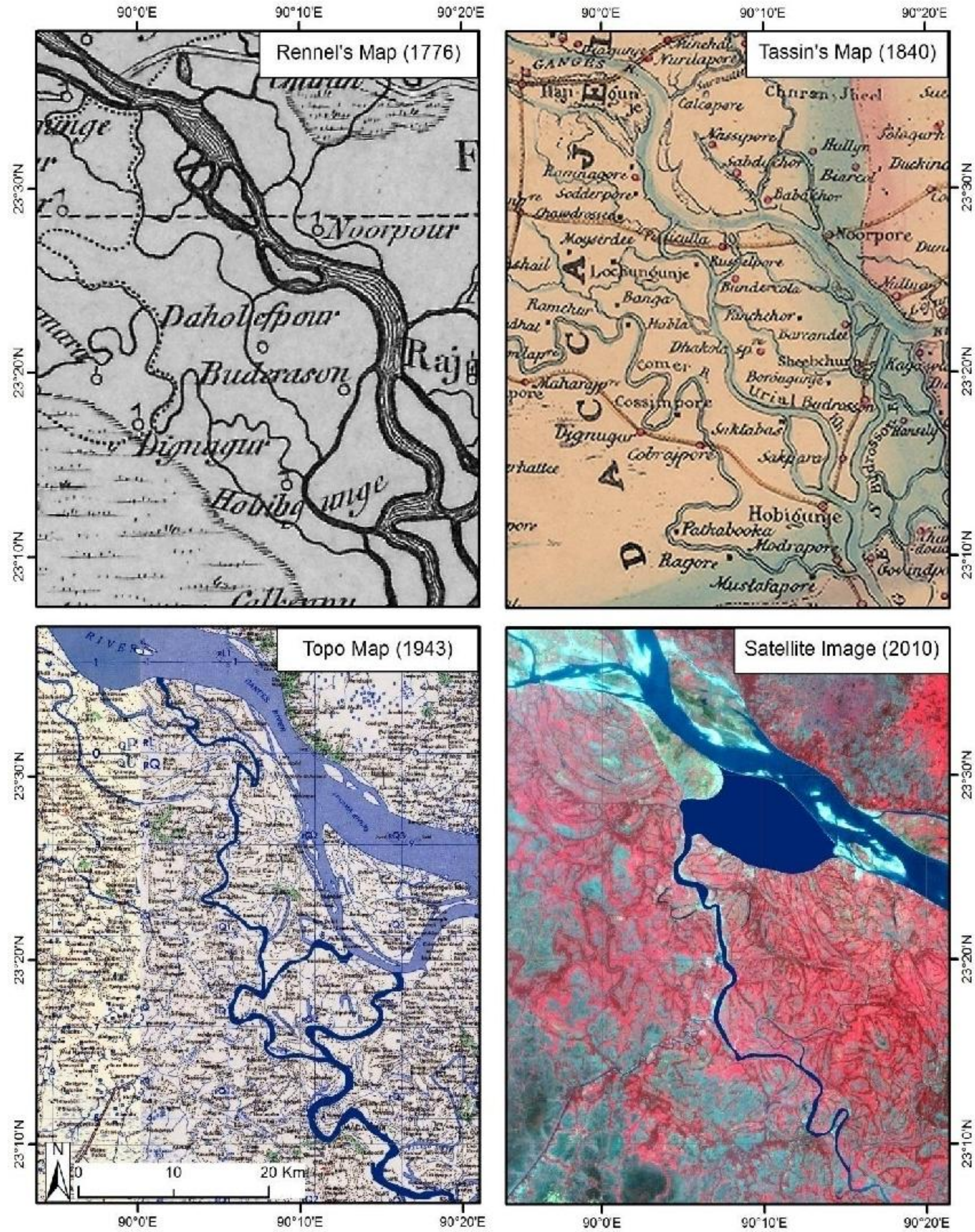

Figure 4.25: Historical development of the Arial Khan and Upper Kumar rivers (CEGIS, 2010)

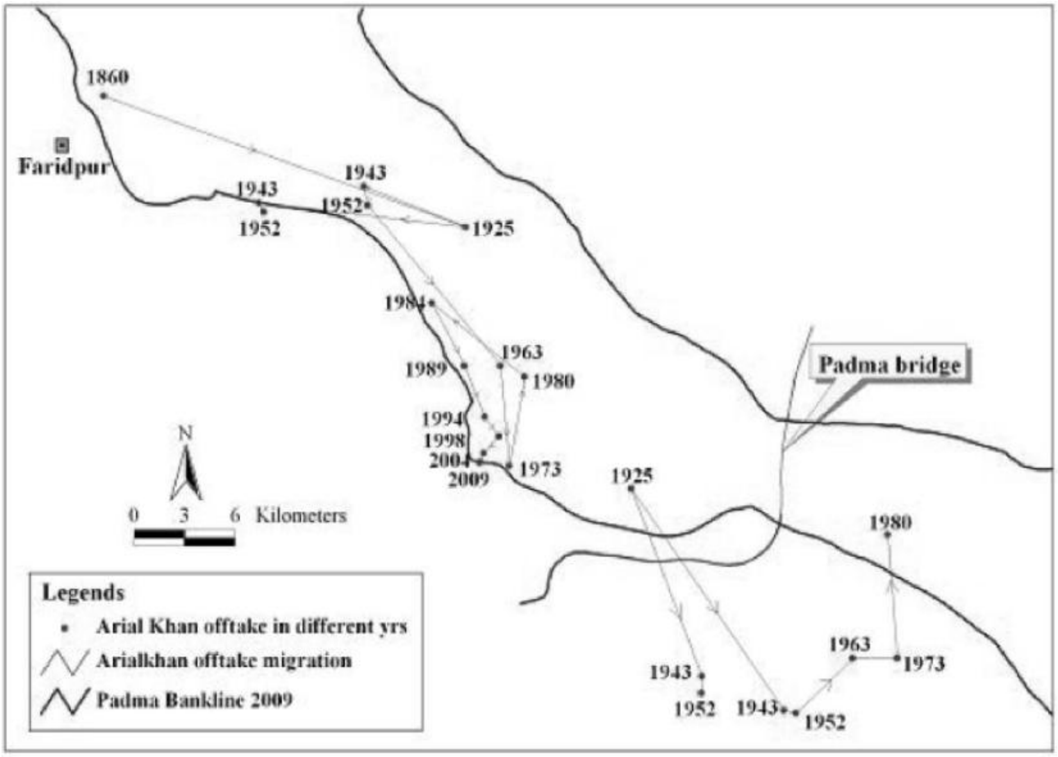

Figure 4.26: Changes in the location of the Arial Khan off-take over time (CEGIS, 2009)

In this region, the Kumar River has abandoned its course at many places in Faridpur and Gopalgonj districts. There are portions of the Kumar even in Chuadhanga, Jhenaidah and Magura districts. From the book of Adams Williams (1919), it is known that the Kumar took off from the Mathabhanga River and drained into the Madhumati River. The map also reveals some reaches of the Madhumati River that had been the original course of the Kumar River. It is thought that Kumar once was a long river which was cut into pieces by different distributaries issuing from the Ganges River at different times. As such the abandoned courses of the Kumar are encountered at different places of the region.

There are several tide dominated large river systems in this region. Starting from the west are the Raimongal, the Arfangasia-Malancha, the Pussur-Sibsa. They mainly comprise saline water system. All these rivers flow through the Sunderbans to meet the bay. Each of these rivers has its respective estuary several kimlometers wide. Due to lack of dry season flow and shallow water effects, tidal pumping processes are very active in this area resulting into rapid sedimentations in the tidal rivers where tidal flux has been reduced due to poldering.

East of the Sunderbans, there are estuaries of the Baleswar, the Payra-Biskhali and the Meghna rivers, which are dominated by fresh water processes, as a result, riverbed sedimentation is less compared to the western estuaries.

Most of the rivers of this region are navigable and play an important role in the regional economies. Many development interventions were done to the river system during the British era and later. Of these, the Helifax Cut, Madaripur Beel Route (MBR), Gabkhan khal, the Mongla-Ghashiakhali Channel (MGC) are mentionable. The Heliflax Cut (1910) connected the Madhumati River with the Nabaganga River. As a consequence of this, for the last hundred years now, almost the entire flow of the Madhumati River is passing through the Nabaganga River. The 23 km MBR was excavated during 1910-12 and due to this fresh water from Arial Khan River is flowing into the Madhumati River. The MGC was excavated in 1974 to connect Mongla with the Ghasiakhali. Moreover, many infrastructures were built between 1960 and 1970 in the coastal region of Bangladesh. As such, many rivers were closed and as the adverse effect of the polders and shrimp cultivation, many other silted up. The Hamkura, Bhadra and Kobadak rivers are few of those several affected others. The description of some major rivers of this region along with problems is given in the next section.

The Gorai

The Gorai River is one of the right bank distributaries of the Ganges. It is the main source of sweet water in the southwest region of Bangladesh. The river is about 86 km long and the width is around 280 m. This river also plays an important role in maintaining the ecosystem of the world's largest mangrove forest, the Sundarbans. Before meeting with the Nabaganga-Madhumati confluence, the Gorai River flows through Kushtia, Rajbari, Jhenaidah, Faridpur, Narail, Magura and the Gopalganj districts through the passage of its course.

Since 1975, after the commissioning of the Farakka Barrage in India, the dry season flow has been reduced, drastically. Morphological changes in the Ganges at the Gorai off-take also have impacted the flow through the Gorai, which has caused the steady declining of dry and monsoon flow during the last three decades. The impact of such hydro-morphological changes of the Gorai river system is quite significant in terms of increased salinewater intrusion in the region.

The Arial Khan

The Arial Khan River is the major source of sweet water to the south western region of Bangladesh. Taking off from the Padma, the Arial Khan drains into the Tetulia River towards the Bay of Bengal. The length and average width of the river is about 155 km and 300 m, respectively. The river is very dynamic and erosion is observed along either of its banks. The river flows through Faridpur, Madaripur and Barishal districts in its course. Fresh water flow is available throughout the year in this tidal river. Water overflows its banks during the monsoon. Navigation facility is available throughout the year. However, in some years, only base flow feeds the river during dry season. Near about 1% flow of the Padma is diverting to the Arial Khan during dry season and it increases to 4% during monsoon. A number of cut-offs have occurred in the Arial Khan River within the last three decades. In fact, the underlying soil of the Arial Khan is of the active Ganges Floodplain, which is susceptible to erosion and has higher stream power. The erodible material of the Active Ganges Floodplain makes the Arial Khan River very vulnerable to erosion and cut-off.

The rate of erosion and accretion along the banks of the Arial Khan River is measured as several hundred sq-meters every year. Accretion is also a governing issue in this area; these lands are of no use due to huge sand deposition. Therefore, erosion and accretion are both issues of concern. Moreover, Navigation in the Arial Khan has been considerably deteriorating since the last decade.

The Bhairab-Kapatakkhya

It is thought that the Bhairab was a major distributary of the Ganges River in the past. This river, as part of the distributary system, would maintain link with the present Bhairab at the downstream. It now enters Bangladesh through the Meherpur District. This is a seasonal meandering river has some tidal influence. The river meets with the Malancha River before entering into the bay.

The Kumar (Faridpur-Gopalganj)

The Kumar in Faridpur and Gopalganj districts is not a single river; rather it is a river network. The present Kumar (Faridpur-Gopalganj) takes off from the Padma and the off-take of the river is controlled through a regulator. Some reaches of the river are fed directly from the Padma River and some reaches are fed from local catchments.

Disconnection with the parent rivers or insufficient flow through the sluice/regulator is the main problem of the river. Some reaches of the Kumar River have become fully disconnected and local rainfall is the only source to feed them. These reaches are used for decomposing jute and that pollutes the water and environment. Most of the local navigation routes are closed due to insufficient depth and connectivity with other rivers or khals. Presently, the river has declined so much that the beel area has become its catchment for collecting water.

Summary

The South-West and South-Central regions are severely vulnerable in terms of climate change and sea level rise. Climate change will cause increase in inundation depth in this region. Additionally, adjustment of tidal plain with sea level rise will be disrupted due to the polders. Due to lack of fresh water flow for river flushing, salinity is increasing which is a great problem in this region. People living in this region at northern part and south of Satkhira, are poor because of salinity, whereas those of lower part are using deep tubewells where arsenic in the ground water is a particular acute problem. About two centuries ago, the mighty river Padma was flowing along the present course of the Arial Khan River. Hence, the floodplain of the Arial Khan is very young and dynamic, and erosion is observed along both sides of the river. More over erosion and accretion process is a major concern for most of the rivers of this region. Flow and sediment management from upstream parent river play an important role in maintaining the navigability of the rivers as sedimentation problem has become very acute in this region.

Additionally, polders of this region are intensely facing subsidence problem which will become more intensive with climate change. This phenomenon will be intensified as tides are not allowed to enter the polders to carry out the sedimentation process. Thus, it has become very significant to initiate a process to allow tide in a regulated way to carry out the sedimentation process. Moreover, in FAP 4 Study, Ganges Barrage was suggested as a mode of salinity control and flow augmentation in the Garai River in the South-West region.

Summary Table (South-West and South-Central Region)	
Controlling features	• Delta progradation or delta building process • Deltaic subsidence • Human interventions
Major problems	• Increasing salinity • Arsenic in the ground water • Maintaining the navigability of the rivers • Subsidence problem in the polders

4.5. South-East Region

4.5.1. Geographical Setting

The South-East Region is mostly bounded by the Meghna river system (**Figure 4.27**). At present, nine trans-boundary rivers enter from India into Bangladesh and drain into the Meghna and the Sandwip Channel of the Meghna Estuary. The cross border rivers are the Sonai, Howrh, Bijni, Salda, Kakri, Dakatia, Selonia, Muhuri and the Feni. The important rivers in this region are the Gumti, Titas, Dakatia and the Little Feni. The topography of the Titas floodplain shows that this area is higher than the surroundings and is an uplifting one. The Titas issuing from the Meghna River reunites with the parent river near Nabinogor. In the past, the Titas was a large river. It has formed a 2-5 km wide terrace in its floodplain. The tributaries the Sonai, the Lohar, the Howra and the Bijni rivers have out-fallen into the Titas River. Now a day, two courses of the Titas River are observed (BWDB, 2011).

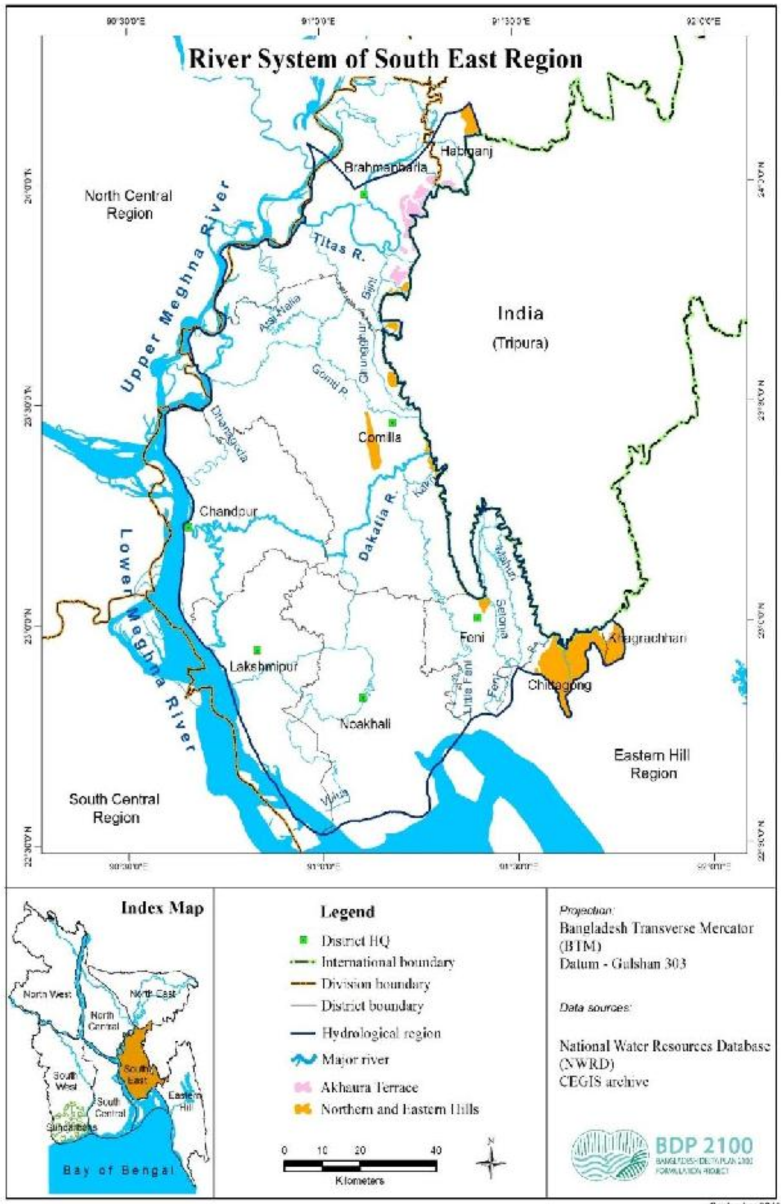

Figure 4.27: Rivers in the South-East Region

4.5.2. Topographical Setting

During the monsoon, huge volume of water flows through the system and causes flooding due to higher level of the sea. The normal vertical tidal range along the coast is generally up to 2m above mean sea level, although in the monsoon season the effects are generally masked on the floodplain by river flooding. Tidal surges, associated with cyclones in the Bay of Bengal, can be up to 3 m above normal high tide levels (**Figure 4.28**).

The surface profile of the Section SE-1 (**Figure 4.29**) shows that the level of Old Meghna Estuarine Floodplain is more than 4 m higher than that of the adjacent floodplains. The Titas, Buri and the Bijni rivers flow in this floodplain. The Titas River is flowing on an elevation of 4 mPWD and has formed a terrace as visible in the DEM. The Section SE-2 denotes that the Dakatia River flows at a level of about 3.5 mPWD. In the SE-3 profile, the Old

Meghna Estuarine Floodplain has a higher land slope than that of Meghna (lower) River floodplain. The Dakatia River is flowing at a level of about 6 mPWD at the meeting point of section SE-3.

The north south surface profile of SE-4 (**Figure 4.30**) shows that the level of maximum part of the Old Meghna Estuarine Floodplain is more than 4 m higher than that of the adjacent floodplains. The Dakatia, Gomti, Buri and the Titas rivers are flowing in this floodplain. The Dakatia River is flowing on an elevation of about 4 mPWD. The Gomti River flows at a level of more than 5.5 mPWD. The Titas River also flows at a level of more than 5 mPWD. High level in the Young Meghna Estuarine floodplain has caused drainage congestion in the middle section of the profile.

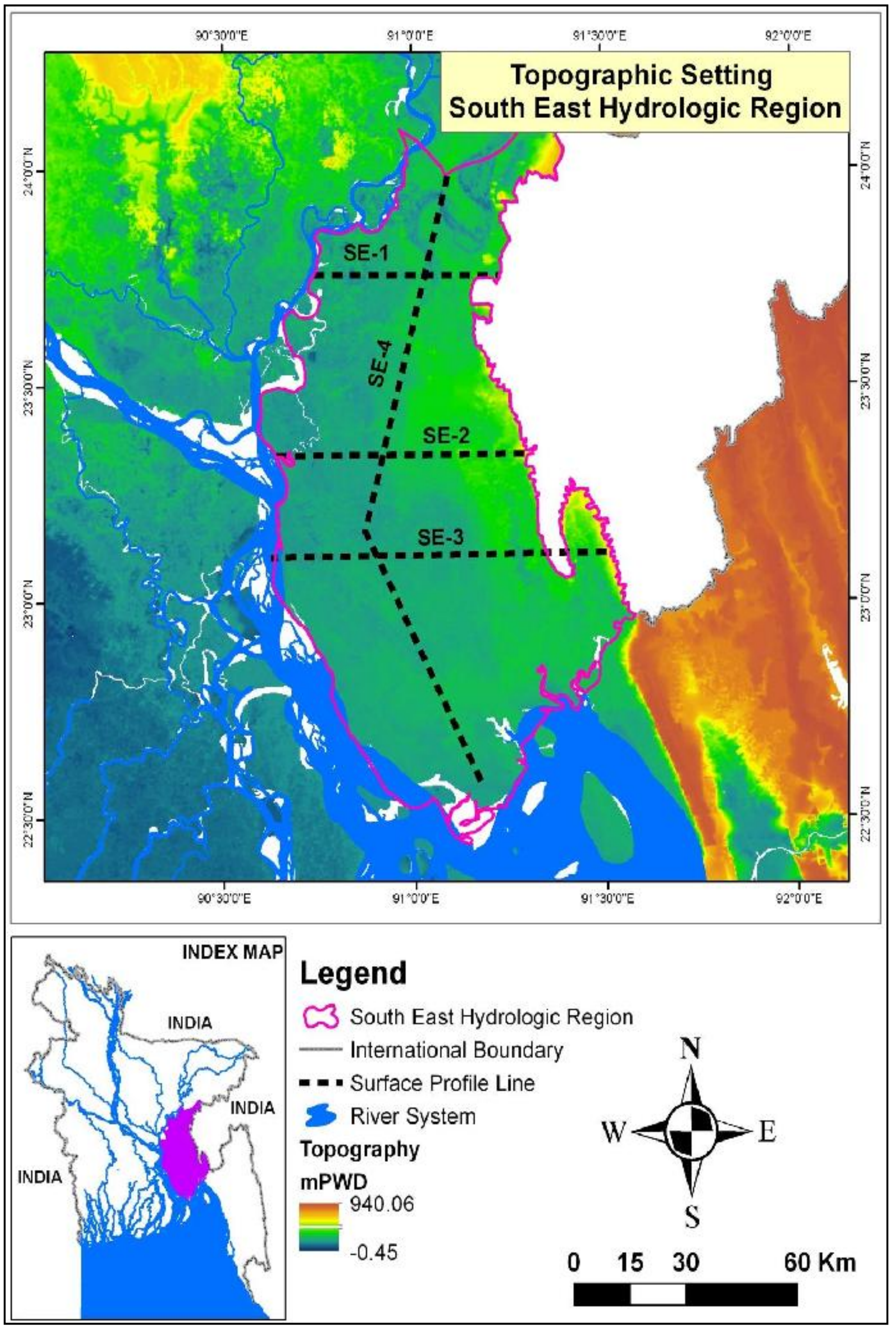

Figure 4.28: Topographical setting of the South-East Region

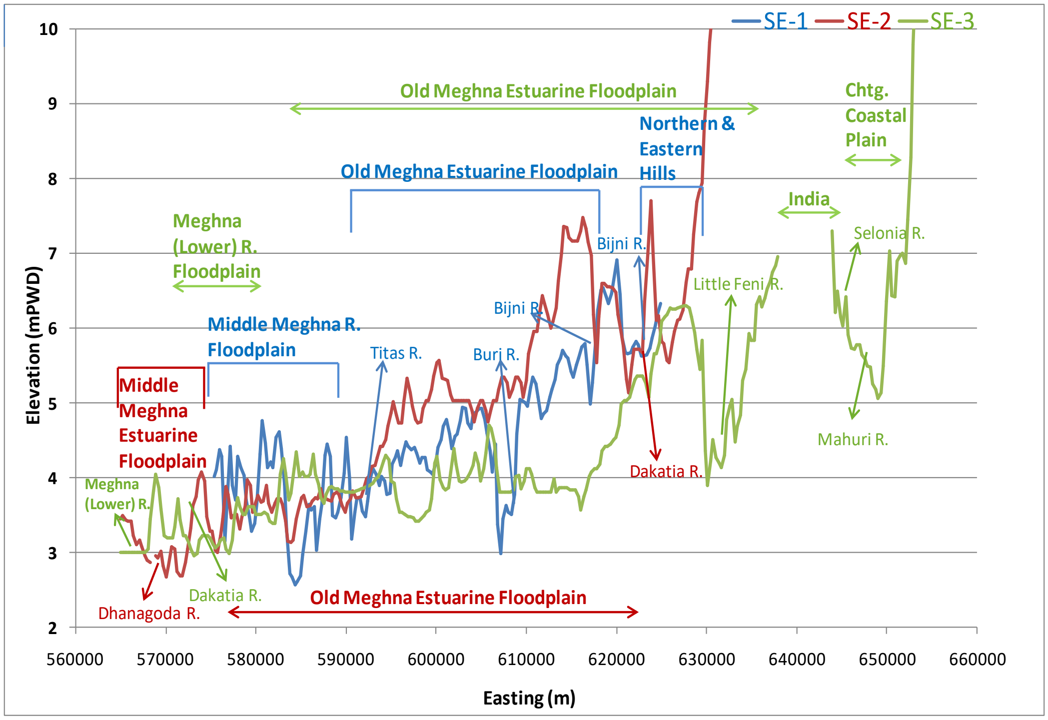

Figure 4.29: East west surface profiles in South-East Region of Bangladesh

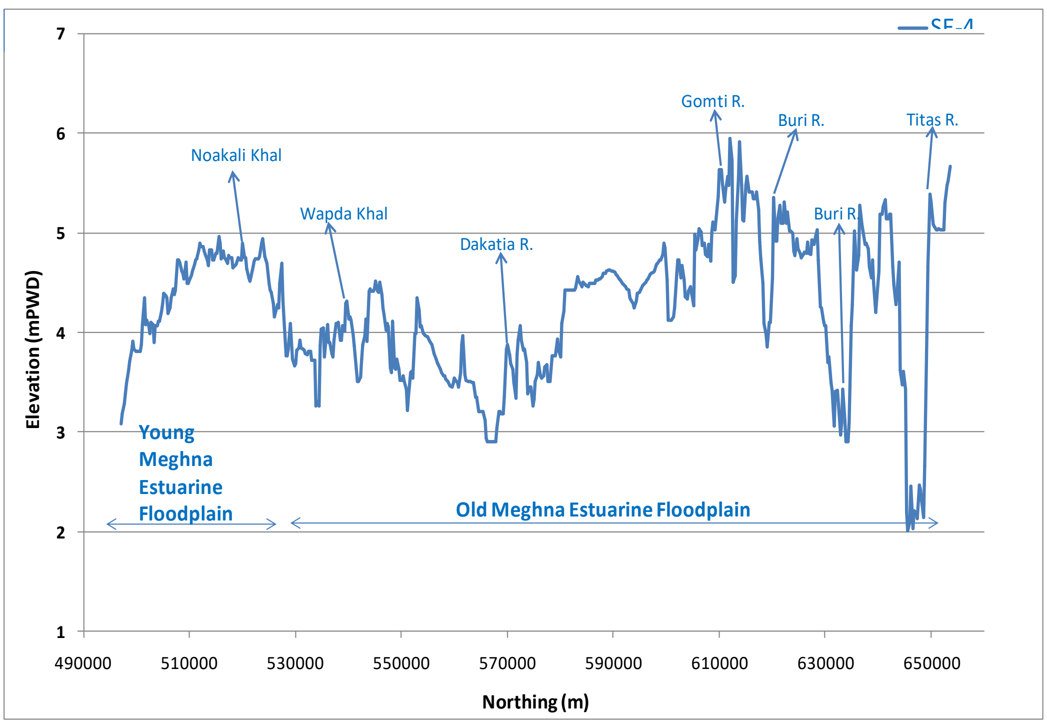

Figure 4.30: North south surface profiles in South-East Region of Bangladesh

4.5.3. Historical Development and Problems

The rivers in this region are not dynamic compared to the other regions of Bangladesh. So their planform has not changed significantly during the course of time. Topograhy of the eastern margin of this region is largly influenced by the north-south aligned underlained folds. Drainage condition of a very large area between successive anticlines of this region has been deteriorated with time. Rapid delta progradation with higher elevation than the existing land, along south margin of this region and uplifted folds are probably the reasons for the deterioration of the drainage condition. Moreover, the recently deposited sediment in Noakhali has developed as an elevated part due to the tidal amplification (**Figure 4.30**). As a result the drainage problem has become more acute.

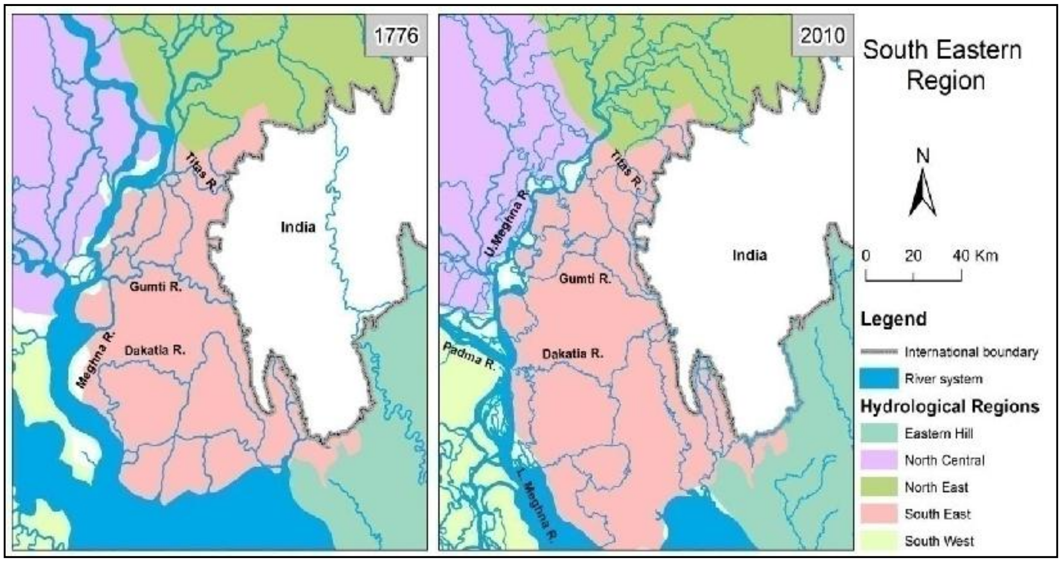

Figure 4.31: Historical evolution of rivers in South-East Region

The description of some major rivers of this region along with problems is given in the next section.

The Titas

The Titas is one of the important rivers of the South-East region of Bangladesh. The river has originated from the Meghna (Upper) River in Brahmanbaria District and again flows back to the Meghna (Upper) River. The 130 km long river has an average width of about 152 m. The river has formed terrace which is one of the prominent features of the river and is much lower than the adjoining floodplain of both sides. The river has perennial flow but reduces significantly during February-March period. Presently, the upstream flow of the river has reduced due to sedimentation at the offtake.

The area is liable to deep flooding from overbank spillage from Titas and Meghna rivers. Adjoining terrace of both sides are flooded during monsoon. Improvement of navigation facilities in the upstream part is the major concern regarding the Titas River which if implemented will enhance develop commercial activities in the area. Agricultural activities of the areas surrounding the Titas are mainly dependent on the irrigation water extracted by power pump from the river. Siltation in the upstream of the river is also hampering irrigation activities of the areas.

The Dakatia

The Dakatia River has originated from hilly areas of West Tripura district of India and entered Bangladesh at Sadar Dakshin Thana of Comilla District. After flowing about 6 km southwestward from the international boundary, a branch of the river -Chauddagram khal, has emerged to meet with the little Feni River. The length of the river is about 141 km and the average width is around 67m. At present, the major source of flow of the Dakatia River is a channel which is connected with the Gumti River. Flowing through Comilla and Chandpur districts, the river has divided into two branches. One branch is flowing southward and the other is flowing westward. Both the branches fall in the Lower Meghna River.

Navigation is very important in the Dakatia River specifically for commercial purpose. Various products and commodities like cement, fertilizer, rice etc. are transported through the river. Many people are involved in sand business and sand is transported from Meghna River through this river. But deterioration of navigation facilities has been observed in some locations. Drainage congestion was also a major concern in the upstream reach of the river before the implementation of South Comilla and North Noakhali Drainage Project. Proper maintenance and monitoring is required in this regard.

Summary

The major problems of this region are flooding and drainage congestion due to the uplifting characteristics of the region. Navigation problems are available in the upstream part of some rivers which is impeding commercial activities. The agricultural activities of this region are mainly dependent on the irrigation water extracted from rivers by power pump. Thus, upstream siltation may hamper these activities.

Drainage congestion affects crop production in both the pre-monsoon and main monsoon periods. The drainage congestion has aggravated by ungated irrigation offtakes.

Summary Table (South-East Region)	
Controlling features	• High level of the Young Meghna Estuarine floodplain
Major problems	• Flooding and drainage congestion • Navigation problems are available in the up stream part of some rivers • Upstream siltation

4.6. Eastern-Hill Region

4.6.1. Geographical Setting

The Eastern-Hills region comprises the Chittagong Coastal Plain and the Chittagong Hill Tracts (CHT), combining the districts of Rangamati, Khagrachhari and Bandarban. Cyclone risks are high in the Chittagong Coastal Plain. The CHT is the only extensive hill area in Bangladesh bordering Myanmar on the southeast, the Indian state of Tripura on the north, Mizoram on the east, and Chittagong district on the west. The area of the CHT is about 13,184 km^2, which is approximately one-tenth of the total area of Bangladesh. They rise steeply, thus looking far more impressive than their height would imply. Most of the ranges have scarps in the west, with cliffs and waterfalls. It contains a man-made lake called Kaptai Lake which has been created for Karnafuli Hydro-Electric Project.

Presently, the region is separated from Myanmar by the Tuilanpui River (**Figure 4.32**). The Kasalong, the Mainy and the Chengy rivers originating from the hill slopes, flow due south from the north and drain into the Kaptai Lake. The elevations of these river catchments are above 500 m. The three border rivers, the Sangu, the Matamuhuri and the Naf, common with Myanmar, are situated in the southernmost extremity of the country (BWDB, 2011).

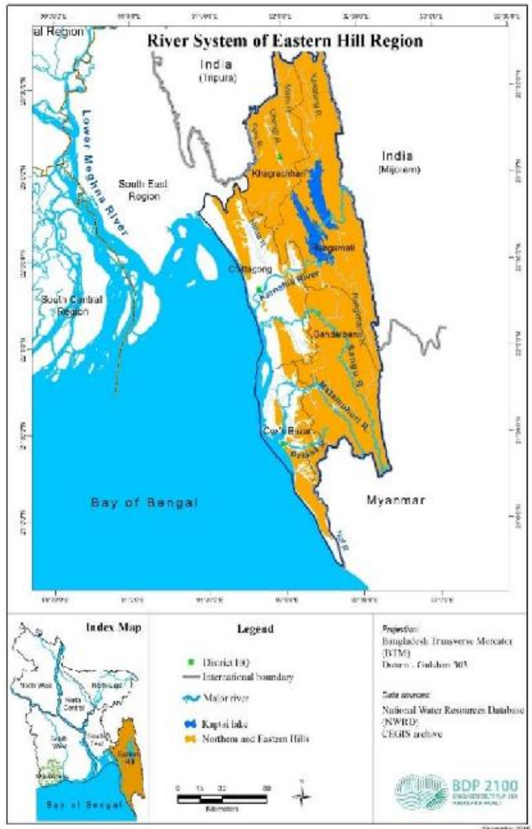

Figure 4.32: Rivers in the Eastern Hills Region

4.6.2. Historical Development

The topography of the region being different from the rest of the country, the rivers of the region are different as well (**Figure 4.33**). These rivers did not change the same way as did the rivers of the other regions. Riversin the hilly region mainly follow the terrain of the hills. The folds of the region's hills being north-south aligned the rivers flow in a north-south direction.

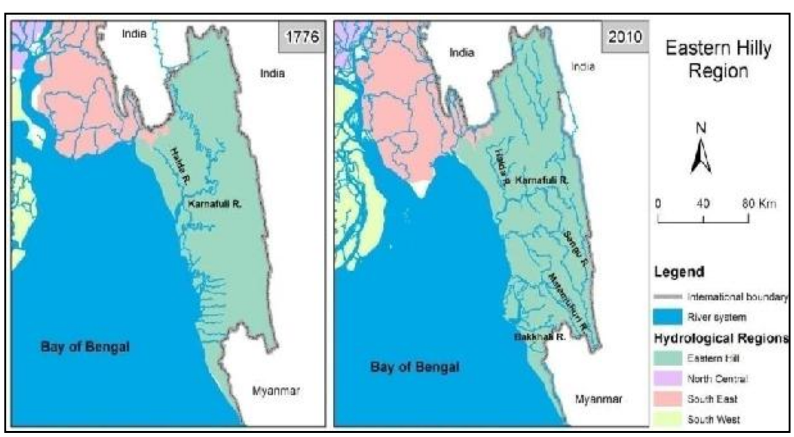

Figure 4.33: Historical evolution of rivers in Eastern Hills

The region is characterized by a huge network of trellis and dendritic drainage consisting of some major rivers draining into the Bay of Bengal. The major rivers are the Karnafuli, the Sangu, the Matamuhuri and the Feni. The Karnafuli River has several important tributaries: Chengi, Kasalong and Rainkhiang.

The description of some major rivers of this region along with problems is given in the next section.

The Karnafuli

The main river of the region, the Karnafuli originates from the Lushai hills. The river is flashy in nature and around 131 km long. Rainkhiang, Kasalong, Thega, Ichamati and Halda are its main tributaries and Saylok and Boalkhali are its major distributaries. Many streamlets are also connected with the river. The flow of the river is dependent on the rainfall at the upper huge hilly catchment area. The river made the most significant change of its course from Kalurghat downwards. Normally, the river had a western and southwestern course. From the extreme corner of the Chittagong port it moves to southwest to fall into the Bay of Bengal.

The main problem of the river is bank erosion around Rangunia in Chittagong Coastal Plains. The river is now facing increasing sedimentation due to deforestation and hill cultivation practices. The upper reaches of the river are shallow and not navigable round the year.

The Sangu

The transboundary river Sangu originates from the Arakan mountain of Myanmar. The river enters Bangladesh from the Bandarban district and outfalls into the Bay of Bengal. The river has tidal effect at the downstream. The length of this river is 294 km and its average width is 120 m at Dohazari. This is a perennial river. The upstream reaches flow through a hilly region and it has less freedom to change its planform. It is a flashy and meandering river and some extend of erosion-accretion occurs in this river.

The Bakkhali

The Bakkhali originates from the hilly area of the Naikhanchhari upazilla of Bandarban district. Flowing through Ramu and Cox's Bazaar upazilas, the Bakkhali River finally outfalls into the Moheshkhali Channel. The Bakkhali River is about 70 km long. In the downstream reach, its average width is 130 m.

The Bakkhali, being a flashy river in nature, shows some common features such as flash floods and floodplain inundations, sinuous characteristics and steep slope from the hilly regions. Erosion and accretion occurs in this river in a very small scale. Recently, in every reach, rate of erosion is decreasing, which could be the effect of the dams on this river.

The Matamuhuri

The Matamuhuri River is a trans-boundary river originating from the Lusai hills in the boundary of Bangladesh and Myanmar at Alikadam upazila of the Bandarban district. The river is 146 km long and its reach average width is 154 m. The river has bifurcated into two channels and has fallen on the Maheshkhali channel. The bifurcated channels towards the Maheskhali have tidal effect. Tributariesof the Matamuhuri River are Bamu Khal, Lama Chara and Popa Chara. A number of rubber dams have been constructed on this river which may have affected the river morphology.

The Matamuhuri, being a flashy river in nature, shows some common features such as flash floods and floodplain inundations, sinuous characteristics and steep slope from the hillyregions.

Summary

In general, most of the rivers of this region are flashy in nature, and erosion occurs along the banks. Sedimentation due to deforestation and hill cultivation practices causes navigation problem.

Summary Table (Eastern-Hills Region)	
Major problems	• Bank erosion • Sedimentation due to deforestation and hill cultivation practices causes navigation problem

5. Institutions, Policies, Strategies and Plans

5.1. Institutions

5.1.1. Institutional Development Overtime

Historical evidences revealed that institutional coordination plays distinct positive roles in every management sector. So, it is important to understand the existing water institutional arrangement and their changes over time to find out the sustainable solution for long lasting water management solutions. A brief chronological evolution of the institutions in water sector in Bangladesh since 1950s is described below.

Disastrous floods of 1954, 1955 and 1956 focused world attention on the importance and need for flood control and water management in Bangladesh (the then East Pakistan). With assistance from the UNDP, the Krug Mission reviewed the situation in 1957 and concluded that water resources development was essential for higher agricultural production and flood control was the central issue. Following the recommendation of Krug Mission report in 1959 EPWAPDA (now Bangladesh Water Development Board and Bangladesh Power Development Board), was created to plan, design, construct, operate and maintain comprehensive water development schemes. Recognizing the importance of other agricultural inputs, East Pakistan Agricultural Development Corporation (EPADC) (now Bangladesh Agricultural Development Corporation) was created in 1961, to provide seeds, fertilizers, pesticides, power pumps and other production inputs for the farmers.

In 1966, the International Bank for Reconstruction and Development (IBRD) reviewed the 1964 IECO Master Plan developed by the then EPWAPDA. The report agreed with the general principles regarding the importance of flood control, drainage and irrigation. The IBRD expressed serious reservations to the suggested strategy and specific proposals of the plan. The IBRD review of 1964 IECO Master Plan played an important role in taking decisions by many donor agencies for not to finance big, complex and long gestation schemes (Faruque, 1990).

The IBRD completed a study in 1972 to provide a basis for post-liberation development programmes in water and agriculture sectors. The proposed strategy emphasized the need for quick results from water development efforts in order to achieve food grain self-sufficiency to meet the requirements of the rapidly increasing population in the backdrop of declining financial resources (Faruque 1990). It attached high priority to small and medium size, simple, low cost, labor intensive projects in shallow flooded areas. Such schemes would involve low embankments and gravity drainage, requiring simple and less sophisticated technology. However, government did not accept the study in its totality but the strategy of the government in the water development sector was greatly influenced and guided by both the IBRD review of 1964 IECO Master Plan and IBRD Land and Water Resources Sector study reports (Faruque, 1990). The need for a new, more comprehensive and multi-sectoral NWP has been recognized by the Government of Bangladesh (GOB). The Master Plan Organization (MPO) was created in 1983 to prepare the NWP. The MPO has prepared the NWP-I in 1986 and NWP-II in 1991. The MPO made an analytical review of the sectoral and cross sectoral issues which is considered a pre-requisite to the formulation of the comprehensive water plan. Finally the MPO became Water Resources Planning Organization (WARPO), an apex organization under the MoWR, under the Act no. xii of 1992. Flood Plan Coordination Organization (FPCO) was created in 1989 to coordinate Flood Action Plan (FAP) activities and has been merged with WARPO in January 1996.

On the other hand, the Joint Rivers Commission (JRC) was established on a permanent basis through a joint declaration between the Prime Ministers of Bangladesh and India on 19 March, 1972 inter-aliato carry out a comprehensive survey of the river systems shared by the two countries, formulate projects concerning both the countries in the fields of flood control and to implement them, to formulate detailed proposals on advance flood warnings, flood forecasting, study on flood control and irrigation projects on the major river systems and examine the feasibility of linking the power grids of Bangladesh with the adjoining areas of India, so that the water resources of the regions can be utilized on an equitable basis for mutual benefit of the people of the two countries. [Source: Official website]. During 1970s, an engineering ''Cell'' was established in the Local Government Division (LGD) under the Ministry of Local Government, Rural Development and Cooperative (MLGRD&C). A Works Program Wing was created in 1982 under the Development Budget to manage works program nation-wide. Then it was reformed into the Local Government Engineering Bureau (LGEB) under Revenue Budget of the Government in October, 1984. Finally, LGEB was upgraded as the Local Government Engineering Department (LGED) in August, 1992 for planning and implementation of local level rural urban and small scale water resources infrastructure development programs. [Source: Official website]

Along with EPWAPDA, the then East Pakistan Government promulgated an ordinance called the East Pakistan Inland Water Transport Authority Ordinance 1958 (E.P. Ordinance, NO LXXV of 1958) to set up an Authority for development, maintenance and control of inland water transport and of certain inland navigable waterways. The BIWTA came in to existence on promulgation of the above ordinance 1958 as the successor of the former East Pakistan Inland Water Transport Authority (EPIWTA). [Source: Official website]

5.1.2. Institutions for River Management

Institutional arrangements reflects shaping governance structure and process for water resources management after referring all policies, rules, laws and organizations. According to MoWR (2001), a total of 35 agencies affiliated with 13 different ministries of the Government are found with functions relevant to water resources management in Bangladesh. Thus, a number of sectoral institutions were formed and remained functional under top-down approach of the Government. At present, the agencies or organisations which have relevant functions in water sector are of four categories: (a) government agencies; (b) local government institutions; (c) other organisations and the private sector; and (d) development partners. A brief description of the existing main agencies is described below based on the NWMP main report:

The National Economic Council (NEC) is the highest executive body in the Government's planning process and is responsible for policy decisions on the basis of recommendations from its Executive Committee (ECNEC).The Planning Commission is a technical body responsible for advising and assisting ECNEC and NEC on development planning. The Planning Commission produces the Five Year Plan, the Three Year Rolling Plan and the Annual Development Programme. WARPO is responsible for water sector planning at national level and acts as the secretariat of the Executive Committee of the National Water Resources Council (ECNWRC). It is also responsible for establishing and maintaining the National Water Resources Database, a management information system and for coordinating water sector developments. The Joint Rivers Commission is responsible for dealings with India and other co-riparian countries through similar organisations in those countries. BWDB is responsible for the planning and execution of medium and large-scale water resource development projects, river dredging and training, flood forecasting, surveys, data collection and sundry activities. Bangladesh Haor and Wetland Development Board (BHWDB) are responsible for monitoring, coordinating and integrating the haor area schemes of other agencies in the wetland areas. The River Research Institute is responsible for research, especially by means of physical modelling into river behaviour at the national and regional levels.

The BIWTA under the Ministry of Shipping is responsible for maintaining the main inland waterways. The Ministry of Local Government, Rural Development and Cooperatives (MoLGRDC) sets policies for rural development and oversees the functions of local government at all levels through its two divisions, the Local Government Division (LGD) and Rural Development and Cooperatives Division (RDCD). The LGED under the LGD plans and executes rural works. In the water sector, the LGED has mainly focused on small-scale schemes up to about 1000ha.

5.1.3. Coordination among the Institutions

A comprehensive National Water Policy in 1999 has played an important role to influence remarkable changes in water institutions of Bangladesh. After Year 2000, government approach was focused on participatory water management. It becomes the umbrella where many institutions can work together with a specific vision. Before this, there was lack of coordination among government organizations. The international donor agencies influenced the Government of Bangladesh to bring into account all the contemporary common global concerns for wise use and efficient management of water resources in Bangladesh. Proper coordination among these organizations may bring sustainable river management in Bangladesh. The Government intends to follow sound institutional principles andthereby to separate policy, planning, and regulatory functions from implementation and operational functions at each level of government, whilst at the same timeholding each institution accountable for financial and operational performance (NWMP, 2001).

The BWDB and LGED are the lead agencies for water management sector in Bangladesh, whereas the BIWTA plays a significant role in river management. These three organizations are under three different ministries and they are implementing programs and projects almost in an adhoc basis. Along with the gaps among the different ministries, there are gaps within the ministries or single institution as well. Like, in the BWDB, for managing the Jamuna River, the west bank is under ADG (West) and the east bank is under ADG (East); whereas the activities for planning anddesign are under ADG (Planning). Hence, a sustainable solution may not be achieved under different management of the same organization. Hence, riverwise development is very imperative. Lack of dedicated office and staff for planning, designing, and implementing may create the key gap for coordinating the development works. So, the BWDB Board, The MoWR and the Ministries of Esatablishment and Planning have approved to establish the Office of the Chief Engineer River Management (CERM). This dedicated section is expected to promote innovation with specialised skills and knowledge. The GoBintends to allow framework DPPs with block allocations for consistency that would allow adaptive construction and management. Lack of stakeholder participation in policy level and implementation level for finding out the specific requirement of the project and gaps is another institutional gap. In addition, lack of capacity development of the staffs in all sectors is hampering to strengthen the organization for planning, designing and implementing.

5.2. Policies and Strategies

There are a number of policies and strategies for theWater Sector. Among these, the review of most relevant policies and strategies are given below.

5.2.1. National Environmental Policy, 1992

The GoB has realized that implementation of government's commitment to environment and mitigation of other environment related problems are possible only through a well defined national policy. National Environmental

Policy has been prepared in 1992 to adequately address the issues concerning to improve the environment in an integrated manner. Section 3.5 "Water Development, Flood Control and Irrigation" of the policy is related to the present study. The Policy directives of this section are given below:

"Water Development, Flood Control and Irrigation:

- Ensure environmentally sound utilization of all water resources
- Ensure that water development activities and irrigation net-works do not create adverse environmental impact.
- Ensure that all steps taken for flood control, including construction of embankments, dredging of rivers, digging of canals etc. be environmentally sound at the local, zonal and national levels.
- Ensure mitigation measures of adverse environmental impact of completed water resources development and flood control projects.
- Keep the rivers, canals, ponds, lakes, haors, baors and all other water bodies and water resources free from pollution.
- Ensure sustainable, long term, environmentally sound and scientific exploitation and management of the underground and surface water resources.
- Conduct Environmental Impact Assessment before undertaking projects for water resources development and management."

Observations

According to the policy directives of Section 3.5.3,GoBhas taken firm positive steps to relocate the tannery industries at Savar with establishment of Central Effluent Treatment Plan (CETP). Government has issued order to the owner of the tannery industries to shift their industries by March 2015. DOE has taken initiatives to impose fines to the owners of the industries that pollute water. Implementation of such initiatives has to be continued and ensured.

5.2.2. National Water Policy (NWPo), 1999

The National Water Policy was declared by the government in 1999. It has 17 sections dealing with policy directives for particular issues. Among the sections which can be linked to the river system management and trans-boundary issues are:

Section 4.1 River Basin management,

Section 4.2 Planning and management of water resources

Section 4.3 Water rights and allocation

Section 4.8 Water and industry

Section 4.9 Water and fisheries and wildlife

Section 4.10 Water and navigation

Section 4.11 Water for hydropower and recreation

Section 4.12 Water for the environment

Section 4.13 Water for preservation of haors, baors, and beels

The specific policy directives related to river management are mentioned below.

River Basin Management

Quated

a. Work with co-riparian countries to establish a system for exchange of information and data on relevant aspects of hydrology, morphology, water pollution, ecology, changing watershed characteristics, cyclone, drought, flood warning, etc., and to help each other understand the current and emerging problems in the management of the shared water sources.

b. Work with co-riparian countries for a joint assessment of all the international rivers flowing through their territories for better understanding of the overall basins' potentials.

c. Work jointly with co-riparian countries to harness, develop, and share the water resources of the international rivers to mitigate floods and augment flows of water during the dry season.

d. Make concerted efforts, in collaboration with co-riparian countries, for management of the catchment areas with the help of afforestation and erosion control for watershed preservation and reduction of land degradation.

e. Work jointly with co-riparian countries for the prevention of chemical and biological pollution of the rivers flowing through these countries, by managing the discharge of industrial, agricultural and domestic pollutants generated by human action.

Planning and Management of Water Resources

Quated

c. The NWMP and all other related plans will be prepared in comprehensive and integrated manner, with regard for the interests of all water-related sectors. The planning methodology will ensure co-operation across sectors and people's participation in the process.

d. Sector agencies of the Government and local bodies will prepare and implement sub-regional and local water-management plans in conformance with the NWMP and approved Government project appraisal guidelines. The Executive Committee of the National Water Resources Council (ECNWRC) will resolve any interagency conflict in this regard.

i. Make social and environmental assessments mandatory in all development plans.

j. Undertake comprehensive development and management of the main rivers through a system of barrages and other structural and non-structural measures.

k. Develop water resources of the major rivers for multipurpose use, including irrigation, fisheries, navigation, forestry, and aquatic wildlife.

l. De-silt watercourses to maintain navigation channels and proper drainage.

m. Delineate water-stress areas based on land characteristics and water availability from all sources for managing dry season demand.**"**

o. Develop early warning and flood-proofing systems to manage natural disasters like flood and drought.

p.i. Regions of economic importance such as metropolitan areas, sea and air ports, and export processing zones will be fully protected against floods as a matter of first priority. Other critical areas such as district and upazila towns, important commercial centers, and places of historical importance will be gradually provided reasonable degree of protection against flood. In the remaining rural areas, with the exception of those already covered by existing flood control infrastructure, the people will be motivated to develop different flood proofing measures such as raising of platform for homesteads, market places, educational institutions, community centers, etc. and adjusting the cropping pattern to suit the flood regime.

p.ii. In future all national and regional highways, railway tracks, and public buildings and facilities will be constructed above the highest ever-recorded level of flood in the country. This principle will also apply in cases of reconstruction of existing structures of this nature.**"**

q. Undertake survey and investigation of the problem of riverbank erosion and develop and implement master plans for river training and erosion control works for preservation of scarce land and prevention of landlessness and pauperization.

r. Plan and implement schemes for reclamation of land from the sea and rivers.

Water Rights and Allocation

Quated

b. In general, the priority for allocating water during critical periods in the water shortage zones will be in the following order: domestic and municipal uses, non-consumptive uses (e.g. navigation, fisheries and wild-life), sustenance of the river regime, and other consumptive and non-consumptive uses such as irrigation, industry, environment, salinity management, and recreation. The above order of priority could however be changed on specific socio-economic criteria of an area by local bodies through local consensus.

g. In specifying surface water rights, the minimum requirement of stream-flow for maintaining the conveyance channel will be ensured.

Water and Industry

Quated

d. Industrial polluters will be required under law to pay for the cleanup of water-body polluted by them.

Water and Fisheries and Wildlife

Quated

b. Measures will be taken to minimize disruption to the natural aquatic environment in streams and water channels.

c. Drainage schemes, to the extent possible, will avoid state-owned swamps and marshes that have primary value for waterfowl or other wildlife.

d. Water bodies like baors, haors, beels, roadside borrow pits, etc. will, as far as possible, be reserved for fish production and development. Perennial links of these water bodies with the rivers will also be properly maintained.

e. Water development plans will not interrupt fish movement and will make adequate provisions in control structures for allowing fish migration and breeding.

Water and Navigation

Quated

a. Water development projects should cause minimal disruption to navigation and, where necessary, adequate mitigation measures should be taken.

b. Minimum stream-flows in designated rivers and streams will be maintained for navigation after diversion of water for drinking and municipal purposes.

c. Dredging and other suitable measures would be undertaken, wherever needed, to maintain navigational capability of designated waterways.

Water for Hydropower and Recreation

Quated

a. Mini-hydropower development schemes may be undertaken provided they are economically viable and environmentally safe.

b. Recreational activities at or around water bodies will be allowed provided it is not damaging to the environment.

Water for the Environment

Quated

a. Give full consideration to environmental protection, restoration and enhancement measures consistent with the National Environmental Management Action Plan (NEMAP) and the National Water Management Plan (NWMP).

b. Adhere to a formal environmental impact assessment (EIA) process, as set out in EIA guidelines and manuals for water sector projects, in each water resources development project or rehabilitation programme of size and scope specified by the Government from time to time.

c. Ensure adequate upland flow in water channels to preserve the coastal estuary eco-system threatened by intrusion of salinity from the sea.

d. Protect against degradation and resuscitate natural water-bodies such as lakes, ponds, beels, khals, tanks, etc. affected by man-made interventions or other causes.

e. Completely stop the filling of publicly-owned water bodies and depressions in urban areas for preservation of the natural aquifers and environment.

f. Take necessary steps to remove all existing unauthorized encroachments on rivers and watercourses and to check further encroachments that cause obstructions to water flows and create environmental hazards.

g. Stop unplanned construction on riverbanks and indiscriminate clearance of vegetation on newly accreted land.

i. Enforce the "polluter pay" principle in the development of regulatory guidelines for all regulatory actions designed to protect public health and the environment.

j. Provide education and information to the industrial and farming communities on self administered pollution control mechanisms and their individual and collective responsibilities for maintaining clean water sources.

Water for Preservation of Haors, Baors and Beels

Quated

a. Natural water bodies such as beels, haors, and baors will be preserved for maintaining the aquatic environment and facilitating drainage.

b. Only those water related projects will be taken up for execution that will not interfere with the aquatic characteristics of those water bodies.

Observations

The NWPo, 1999 may be revised taking the following into considerations:

- Decisions taken in the recent SAARC summit (2014) about the investments in hydropower generation, transmission and river management
- For sustainable supply of drinking water, construction of desalinization plant in the coastal areas and encouragement of private entrepreneurs
- Development of piped water supply system in the small cities along the rivers utilizing the surface water
- Construction of small hydro power plants utilizing run-off river technology and encouragement of private entrepreneurs
- The issues of river encroachment
- Proactive measures including the settlement of legal issues through special courts or tribunals.
- Impact of climate change

5.2.3. Coastal Zone Policy, 2005

The GoB formulated Coastal Zone Policy (CZPo) in 2005. Its major objective is to provide a general guidance to all concerned for the management and development of the coastal zone in a manner, so that the coastal people are able to pursue their lives and livelihoods within secure and conducive environment. There are eight sections in this policy. Among those, the related sections are -

Section 4.3: Reduction of vulnerabilities

Section 4.4: Sustainable management of natural resources

Section 4.8: Conservation and enhancement of critical ecosystems

The directives related to this study are presented below.

Reduction of Vulnerabilities

Quated

b. Integration will be made with 'Comprehensive Disaster Management Plan' on aspects concerning the coastal zone

d. Effective measures will be taken for protection against erosion and for rehabilitation of the victims of erosion

f. Sea-dykes will be regularly maintained as first line of defense against storm surges and afforestation on it according to the existing policy;

g. Earthquake management will be strengthened and capacity to cope with earthquakes will be enhanced.

Sustainable Management of Natural Resources

Water

Quated

a. Adequate upland flow shall be ensured in water channels to preserve the coastal estuary ecosystem threatened by the intrusion of soil salinity from the sea;

b. Small water reservoirs shall be built to capture tidal water in order to enhance minor irrigation in coastal areas. Appropriate water management system within the polder utilizing existing infrastructures will be established for freshwater storage and other water utilization;

Conservation and Enhancement of Critical Ecosystems

Climate Change

Quated

a. Existing institutional arrangements for monitoring of climate change in Bangladesh will continue. Steps will be taken to support upgrading of technology and institutional strengthening for enhancing their capacity for generation of better data and more accurate long-term prediction and risk related to climate change;

b. Implementation of adaptive measures identified in relation to climate change for coastal zone and resources shall be gradually undertaken;

c. Efforts shall be made for continuous maintenance of sea-dykes along the coastline as first line of defense against predicted sea-level rise;

d. An institutional framework for monitoring/detecting sea level rise shall be made and a contingency plans for coping with its impact.

5.2.4. Bangladesh Water and Flood Management Strategy, 1995

In this strategy, the government has taken both long term and short term strategy. Long term strategy includes undertaking integrated water and land use planning (including flood protection, flood plain zoning, protection against drought and storm surge), achieving inter-sectoral balance, managing cross-border flows, basin wise development, balancing structural and non-structural approaches to water management, setting environmental priorities, and institutional strategies. As short term, it wasdecided to make pilot projects, supporting activities and sub-regional planning, and prepare a comprehensive NWMP, which would be completed by 1998 to provide a sound basis for planning, designing and implementing the future generation of projects and programmes. Preparing national water policy was also included in the short term strategy.

As per the strategy, NWPo was prepared and approved in 1999. WARPO prepared in NWMP in 2001, which was approved in 2004.

5.2.5. Coastal Development Strategy, 2006

The Coastal Development Strategy (CDS) is based on the approved Coastal Zone Policy (CZPo) 2005. It has been prepared for coordinating priority actions and arrangements for their implementation through selecting strategic priorities and setting targets. Another objective is to create institutional environment. It describes governance of the coastal zone. Its planning horizon for specific actions is five years. The CDS is a targeted process and the targeting has been made with respect to region, disadvantaged groups, issues and opportunities. In this strategy, there are nine strategic priorities, evolved through a consultation process, guides interventions and investments in the coastal zone. Among them, this study related strategies are:

- ensuring availability of fresh and safe water
- safety from man-made and natural hazards
- optimizing use of coastal lands
- sustainable management of natural resources: exploiting untapped and less explored opportunities
- environmental conservation

- empowerment through knowledge management
- creating an enabling institutional environment

The three equally important routes towards implementing these strategic priorities have been identified- they are mainstreaming, investments and governance.

Observations

32 Priority Investment Projects (PIP) were identified during preparation of ICZMP and has been mentioned in the (CDS) but so far, only one project regarding land zoning has been implemented by the Ministry of Land.

Moreover, two district plans one for Bhola and other for Cox's Bazaar were prepared but those plans have not been yet implemented.

It is recommended that the plans for these two coastal districts as well as the remaining 31 PIPs should be given priority for immediate detailed study and there after implementation (if found feasible).

5.2.6. Bangladesh National Climate Change Strategy and Action Plan, 2009

The climate change strategy of Bangladesh has included activities in all four building blocks of the Bali Action Plan (2007) namely: adaptation to climate change, mitigation, technology transfer and adequate and timely flow of funds for investment within a framework. For adaptation, the government of Bangladesh with the help of the development partners has invested in flood management schemes, flood protection and drainage schemes, coastal embankment projects etc. and it will continue in future. As a mitigation measure, Bangladesh has two clean development mechanism projects concerned with solar energy and waste management. The GoB has established a National Climate Change Fund with an initial capital of $45 million later raised to $100 million, which will focus mainly on adaptation.

The GoB has established Climate Change Action Plans, which is a 10 year programme (2009-2018) to build the capacity and resilience of the country to meet the challenge of the climate change. According to this action plan, the government will strengthen its capacity to deal with the increasingly frequent and severe natural catastrophes as a result of climate change. It will strengthen forecasting of cyclone, storm surge, as well as flood early warning system. The government will repair and rehabilitate existing infrastructures like coastal and river embankments and drainage systems and ensure effective operation and maintenance of these infrastructures. It will also urgently construct new needed infrastructures to meet the changing conditions. The government will take necessary steps to model the likely hydrological impacts to climate change on Ganges-Brahmaputra-Meghna system to assess likely future system discharge and river levels in order to derive design criteria for flood protection embankments. The government will build capacities of key government ministries and agencies to take forward climate change adaptation. It will also build capacity to undertake international negotiations. Regional and international cooperation is essential for building these capacity and resilience.

5.2.7. Poverty Reduction Strategy Paper, 2009

Quoted

The second Poverty Reduction Strategy Paper "Steps toward change: National Strategy for Accelerated Poverty Reduction II; Revised; FY 2009-11 consists of five strategic blocks and five supporting strategies.

Hazards like floods, cyclones and droughts are noted for aggravating poverty through destruction of food stock and insufficient assets of the poorer households and through making employment opportunities scarce. Poverty, in its turn, often leads to vulnerability to disasters, particularly to floods, riverbank erosion, coastal cyclones and tidal surges.

The strategies of water resources development and management are grouped under six major heads which are

- Dredging of the main rivers and their development for multipurpose use of water resources, management for navigation, erosion control and development of hydropower
- Flood protection and storm-water drainage measures through rehabilitation and maintenance of existing FCD and FCDI systems in a participatory manner and protection of rural and urban areas from floods
- Disaster management programmes including provision of cyclone protection, early warning and forecasting systems with adequate lead time, flood proofing of shelters, control of riverbank erosion, drought management and rationalization of groundwater resources and climate change adaptation
- Adequate provisions for water management for agriculture through public sector irrigation development and flood management and drainage
- Ensuring protection of the natural environment and aquatic resources through water pollution monitoring and control, water management for fisheries and ecologically sensitive areas and raising awareness of all stakeholders for supporting environmental measures
- Ensuring development of institutions in the water sector

5.2.8. Water Act, 2013

The GoB published the Bangladesh Water Act in the gazette on 02 May 2013 where it has been declared that government is the owner of all the water resources of the country including surface water, ground water, sea water, rain water and water in the atmosphere. For this Act, a National Water Resources Council (NWRC) will be formed comprising 34 members. The Prime Minister will head this council and member-secretary will be the Senior Secretary or Secretary to the Ministry of Water Resources (MoWR). The NWRC will give advice to the Government to enter into any Memorandum of Understanding (MOU), agreement, convention, treaty or any other similar instrument with any foreign country or international or regional organization. The GoB will adopt NWPo. The government may include the policies of pricing of water. Until the adoption of the new NWPo, the NWPo (1999), adopted by the Government shall remain in force. There will be a 23 member Executive Committee of the NWRC (ECNWRC). The Minister, Ministry of Water Resources will be the head of the ECNWRC and the member secretary will be the Director General (DG) of WARPO. According to the Act, WARPO will prepare a NWMP. The ECNWRC will issue clearance certificate to the water resources development projects, if they are found consistent with the NWMP. According to the Act, no one can construct any structure on or on the slope of any flood control embankment for ensuring its sustainability, without permission from appropriate authority. The ECNWRC may impose any restriction for ensuring the proper management of water resources. Without permission of the appropriate authority and without complying with the provisions of the Act, no one can store water in any natural or artificial reservoir. The ECNWRC may declare any wetland as flood control zone to ensure easy passage of the flow of floodwater. Violation or ignorance of any order issued under this Act will be considered as punishable offence.

5.3. Major Studies and Plans

The most important studies/reports which have effectively guided the government policy in the water resources sector are:

1) Krug Mission Report, 1957
2) EPWAPDA 1964, Master Plan

3) IBRD review of 1964 Master plan, 1966
4) IBRD Report on Land and Water Resources Sector Study, 1972
5) National Water Plan, 1986
6) National Water Management Plan (NWMP),2004

5.3.1. Krug Mission Report, 1957

A United Nations Technical Assistance Mission (popularly known as Krug Mission) was engaged to study the flood control and water resources development problems.

Krug Mission Report is the first major study which addressed the problem of flood control and water resources development of the country. The report effectively discussed the principles governing delta development by large rivers and pointed out the tendencies of the Ganges-Padma, Brahmaputra-Jamuna and Meghna rivers (Faruque 1990). The interdependence of the projects was emphasized. Frequent mentions were made of the probable effect of projects on the regime of the rivers and the basic problem of siltation in all reaches of these rivers (Faruque 1990). The broad principles of flood protection technology were discussed but specific recommendation for any method or project formulations were beyond the scope of the work.

The principal recommendations, suggestions and observations of the report are presented below based on Faruque, 1990:

1) Steady and persistent efforts to be given to complete the big projects that are under way i.e. Kaptai dam on Karnafuli River and the G.K. project (Kushtia) works.
2) Efforts to be given for sound development of embankment and river training works.
3) Irrigation in dry months, rather than flood abatement would prove the speediest way of securing adequate food production.
4) Major expansion in geological, meteorological and hydrological surveys and investigations, including a complete exchange of basic data with India on all rivers flowing through both the countries, should be made.
5) If found feasible and economically sound, a barrage and irrigation canals on the Teesta, including flood control component should be taken up.
6) Dredging has an important role in works connected with flood control, drainage and irrigation. An efficient fleet of dredgers should be maintained by the government.
7) Power is essential for water development. Country-wide power grid should be planned.
8) Urgent need seen (Commission) for full co-operation between India and Bangladesh (the then East Pakistan) is necessary for solving the problems related to water resources development.
9) A new government corporation with comprehensive responsibility and authority to deal with all water and power development problems should be created.

5.3.2. EPWAPDA 1964 Master Plan

The BWDB (the then EPWAPDA) appointed IECO of USA in 1959, for the preparation of a long term comprehensive Master Plan of the water sector. The plan presents a guide or framework for the development of water and power resources. The water and power development programme was designed to meet requirements for 20 to 25 years.

The report pointed out that agriculture would remain the principal activity of the country for many decades. Target for increase in agricultural production is attainable through efficient use of arable land that is, by improvement of farming practices and the implementation of water resources projects. Water resources projects will provide flood control, drainage and irrigation or combination of these features and hydro-electric power. The IECO identified 63 water development projects and grouped them according to four geographical locations.

Out of 8.75 M.ha of arable land of the country, Master Plan projects aimed to provide flood control and drainage facilities to 4.9 M. ha of land of which 3.2 M. ha would also be provided with irrigation facilities (IECO, 1964).

The proposed sequence of construction was to build and operate the flood protection and drainage works as a first stage, to be followed with irrigation works as a final stage (Faruque, 1990). The report pointed out that "most of the irrigation water will be pumped from the streams until such time as the Ganges and Brahmaputra Barrages become feasible to supply the irrigation systems by gravity. Ground water will be used for irrigation of several areas" (IECO, 1964).

The Master Plan emphatically recommended collection and processing of hydrological and other basic data required for project planning. Further recommendation was made for the plan to be constantly reviewed and be revised at reasonable intervals as per future requirements. It may be mentioned here that the EPWAPDA Master Plan, 1964 so long formed the basic framework of project planning of BWDB.

5.3.3. Bangladesh Land and Water Resources Sector Study (IBRD), 1972.

The Bangladesh Land and Water Resources Sector Study (IBRD) was published in 1972.

The country experienced disastrous flood in 1969 followed by unprecedented cyclone and tidal bore in 1970 and the War of Liberation in 1971. The GoB was engaged in relief, rehabilitation and reconstruction activities. With this scenario in the background, this study was conducted by IBRD (Faruque, 1990).

The study recommended strategy was to undertake, without delay a series of quick yielding, low-cost, labor intensive projects. Concurrently, planning for long term programmes, both in the land and water resources sector and elsewhere in the economy were recommended (Faruque, 1990).

The study concluded that for rapid production growth, emphasis must be given to the following key inputs:

1. High yielding seeds production and distribution;
2. Inputs packages comprising seeds, fertilizer, plant protection and improved draft animal power;
3. Low lift pump irrigation and small drainage improvements;
4. Minor to medium size drainage works;
5. Tube well irrigation and double pumping;
6. Early investigation of increasingly more difficult and major drainage works, including poldering in deeply flooded areas for flood protection and irrigation agriculture.

The study pointed out the need for policy re-orientation in the drainage, flood control and irrigation programmes. It was suggested to take scattered development investment. Further, rural works type approach was also recommended provided they are based on adequate engineering. The study gave emphasis on preparation of regional master plan (Faruque, 1990).

5.3.4. National Water Plan (NWP), 1986.

The planning and implementation of the projects of BWDB are dominantly guided by 1964 IECO Master Plan (Faruque 1990). In the background of development of water resources projects and its performance, changed agro-socio-economic conditions of the country, changed hydrological regime due to implementation of projects in both, India and Bangladesh, the GOB recognized the need for a comprehensive and multi-sectoral (NWP). MPO was created in 1983 to formulate a NWP (Faruque 1990).

Analytical reviews of the sectoral and cross sectoral issues were made. The identified water use sub-sectors are- agricultural, fisheries, navigation, domestic and industrial water supply. The cross sectoral issues include salinity and conflicts and complementarities of development.

For the identification of development opportunities for the NWP, the entire country has been divided into 60 planning areas, each comprising of one or more hydrologic catchment areas. A comprehensive assessment of land and water resources and an estimate of water demand of various water use sub-sectors were made. For the water sector, 15 modes of development were identified with analysis in four major categories (Faruque, 1990). They are:

1. FCD (Flood control and gravity drainage)
2. Irrigation
    a. Major irrigation
    b. Minor irrigation
3. FCDI (flood control, drainage and irrigation)
4. Additional modes

Based on the findings concerning the availability of water resources and estimates of water demand for all uses, development strategies were evolved. Alternative development plans were in turn, formulated based on the strategies.

Based on these strategies, four alternative plans have been drawn. The surface water strategy is the same in all the plans while alternatives have been formulated by varying ground-water strategy.

The recommended surface water strategy is "full development of regional water, mid-term use of the main river and FCD development" MPO (1986). The four alternative ground water strategies range from the low level of development associated with STW, to strategies aimed at full development.

Plan IV has been selected as the recommended NWP with Plan III as an alternative. Plan IV assumes a zoning approach "which limits ground water development by STWs, and Deep Set Shallow Tube Wells (DSSTWs) to those areas or upazilas within a planning area where 95 percent of the ground water potential can be achieved by these modes". All other areas are zoned for deep Tube Wells (DTWs).

The NWP emphasized the need of use of the Ganges and the Brahmaputra waters through barrage projects to meet the increasing demand for irrigation and for production of food. The NWP has recommended starting pre-investment works on these schemes immediately for timely implementation.

5.3.5. National Water Management Plan (NWMP), 2004

Water Resources Planning Organization (WARPO) prepared the draft NWMP in 2001 which was approved by the Government in 2004. The Plan is presented in three phases: Short-term (2000-05) - it is considered a firm plan of ongoing and new activities; Medium-term (2006-10) - it is an indicative plan, and the Long-term (2011-25) which is a perspective plan. Implementation of the plan is to be monitored regularly and it updated every five years. The programmes are grouped into eight clusters and spatially distributed across eight planning regions of the country. The study relates to the eight clusters, namely:

- Institutional Development (ID)
- Enabling Environment (EE)
- Main Rivers (MR)
- Towns and Rural Areas (TR)

- Major Cities (MC)
- Disaster Management (DM)
- Agriculture and Water Management (AW)
- Environment and Aquatic Resources (EA)

Each cluster comprises a number of individual programmes, with a total of identified 84 programmes. The main objectives of these clusters are presented below.

Institutional Development (ID)

"The Government intends to follow sound institutional principles and thereby to separate policy, planning, and regulatory functions from implementation and operational functions at each level of government, whilst at the same time holding each institution accountable for financial and operational performance." The main aims for developing the capacity of the water sector are:

- "The progressive withdrawal of central Government agencies from activities that can be accomplished by local institutions and the private sector, in line with Government's commitment to decentralized decision taking through transparent mechanisms with emphasis on stakeholder participation."
- "To the extent feasible and warranted, contracting out of central Government agency functions."
- Capacity building of Water Sector Organizations such as- BWDB, WARPO, DoE and others.

There are ten programmes in this cluster.

Enabling Environment (EE)

"The Government will progressively develop an enabling environment consistent with sound institutional principles and policy objectives through a series of measures aimed at providing a coherent and comprehensive set of documents that will make clear the rights, obligations and rules of business required for the sector as a whole".

An enabling environment is essential if all the elements of society are to perform efficiently. Necessary actions will be taken in the following areas.

- Existing and new legislation
- Zones, guidelines and procedures
- Participatory planning and management
- Promotion of women's participation
- Media and awareness raising
- Promoting private sector participation
- Regulatory and economic instruments
- Development finance
- Research and information management

In this cluster there are 13 programmes.

Main Rivers (MR)

"In line with NWPo, the main aims for the main river systems are to ensure that they are comprehensively developed and managed for multipurpose use through a variety of measures, including a system of barrages, and other structural and non-structural measures. The Government also intends to work toward international river basin planning to realize the full potential benefits of these rivers." In this cluster the strategies have been discussed under the following headings:

a) Development of surface water resources for multi-purpose use
b) River management for navigation and erosion control
c) Development of hydropower

The main development objective of this cluster is to improve quality of life of people by the equitable, safe and reliable access to water for production, health and hygiene. This cluster has 12 programmes, including regional river management and improvement, Ganges barrage and ancillary works, Meghna barrage and ancillary works, Brahmaputra barrage and ancillary works.

Towns and Rural Areas (TR)

"In the towns (i.e. excluding the major cities) and rural areas, the main aims are, to the extent feasible and affordable, to satisfy increasing demands for safe drinking water and sanitation, and within the towns to provide adequate flood protection and storm water drainage. To achieve this, the principal objectives will be to provide a safe and reliable supply of potable water and sanitation services to all the inhabitants in the towns and rural areas, along with effective facilities for wastewater disposal to safeguard public health and protect the environment." Flood protection will be provided to the economically important upazila and district towns.

"Activities for this sub-sector fall into four categories: water supply, sanitation, flood protection and storm water drainage." There are eight programmes in this cluster. The main programmes are large and small town flood protection, large and small town storm water drainage.

Major Cities (MC)

"The major cities considered are the Statistical Metropolitan Areas (SMA), namely Dhaka, Chittagong, Khulna and Rajshahi. One of the major challenges is to address the development requirements of the urban sector, particularly Dhaka, which is expected to become one of the megacities of Asia". "The main aims for these major cities are, to the extent feasible and affordable, to satisfy increasing demands for safe drinking water and sanitation and provide adequate flood protection and storm water drainage. Options for wastewater management and recycling will be explored."

Activities for this sub-sector fall into following categories: water supply, sanitation, flood protection and storm water drainage, wastewater management and also institutional and financial reforms. There are 17 programmes in this cluster. The programme includes Dhaka flood protection, Chittagong flood protection, Khulna flood protection, Rajshahi flood protection.

Disaster Management (DM)

"Disaster management (including disaster preparedness) involves prevention and mitigation measures, preparedness plans and related warning systems (especially at the Thana level), emergency response measures and post-disaster reconstruction and rehabilitation". "Water-related natural disasters are a relatively common occurrence in Bangladesh. In this context, they are taken to include floods, droughts, cyclones and riverbank erosion". This cluster consists of six programmes including flood proofing in the charland and haor basin, national, regional and key feeder roads- flood proofing, railway flood proofing.

Agriculture and Water Management (AW)

"Bangladesh's overall agricultural policy objective is to expand and diversify agricultural production and to maintain food security, especially with regard to sustaining near self-sufficiency in rice."

Main focus of activities includes the following-

(a) Expansion and support to minor irrigation development

(b) Public irrigation development

c) River maintenance, and

(d) Flood control and drainage

There are eight programmes in this cluster. The main programmes are improved water management at local government level and at community level, land reclamation, coastal protection and afforestation.

Natural Environment and Aquatic Resources (EA)

"The key objectives in relation to the natural environment and fisheries are: to ensure provision of clean water for multipurpose uses; to restore and maintain fish habitats; to ensure provision of water for sustainable use, and preservation of key features of wetlands, and to protect the aquatic environment in the future, especially by institutionalization of EIA and environmental management procedures. Forestry is also an important element of the natural environment, and is an effective means of preventing degradation of upland watersheds". "Bangladesh is signatory to various international conventions and protocols, including the Convention on Biodiversity, Ramsar Convention, Framework Convention on Climate Change, and Convention on Combating Desertification. The Government is committed to fulfilling its obligations under these conventions."

The focal points of activities are listed below:

(a) Water pollution and control

(b) Water management for fisheries

(c) Water management for ecologically-sensitive areas

(e) Supporting environmental measures and

(f) Institutional reform and strengthening

Among the 10 pregrammes of this cluster, the main programmes are: improved water management in the haor basins in the North-East region, environmentally critical areas and integrated wetland management, improved water management and salinity control in the Sundarban.

5.3.6. Observations

There is wide spread perception that NWMP is not being implemented. Although NWMP was approved by the National Water Resources Council (NWRC) but in absence of administrative orders, the NWMP was critically considered as a document of Ministry of Water Resources. Hence, other ministries did not show much interest in the implementation of the plan. This is a framework plan. It was difficult for many organizations to identify projects from this NWMP.

Other criticism is that, it was a donor driven plan. The development partners play a very vital role in the implementation of the projects. GOB /many organizations could not find development partners for financing their projects.

WARPO has been mandated to play the role of clearing house for all water sector projects. In exercising its clearing house function, WARPO scrutinizes all the projects of the BWDB to check whether they have been formulated in accordance with the NWMP. But the projects of other major organizations like Local Government Engineering Department (LGED), Department of Public Health Engineering (DPHE) and Roads and Highways Department (RHD) are not being scrutinized by the WARPO or any other organization to check the conformity of the projects with the NWMP. In absence of administrative orders and/or revision of national planning procedure, WARPO could not discharge its responsibilities of clearing house role for other organization/departments.

According to the NWMP, it [NWMP] should be revised in every 5 year, taking into consideration the changes of infrastructural development, physical conditions, global or regional changes, economic condition etc. Since its approval, the NWMP should have been revised twice.

For successful implementation of the NWMP projects, necessary administrative order/ memorandum should be issued from the Planning Commission and the national project processing procedure should also be modified/ revised accordingly.

The NWMP should be reviewed and revised.

6. Drivers and Challenges

6.1. Past and Present Drivers of Geomorphological Development

Avulsion of the Brahmaputra and the Teesta, gradual shifting of the Ganges, tectonic subsidence and uplifting, deltaic subsidence, and delta progradation are the main drivers that influence the hydro-morphological development of the river systems of Bangladesh. In addition, human intervention, like- construction of dams, barrage, coastal polder, flood embankment, unplanned landuse changes and ground water abstraction, has also triggered the changing processes. However, the active functioning of those drivers varies greatly depending on the regional physical characteristics as well, like the Madhupur Tract and the Barind Tract. Moreover, seismic events, like- 1950 Assam earthquake (8.5 Richter scale), have pronounced effect on the delta building process. Huge sediment generated by the earthquake has expedited the delta building process through delta progradation, which is also responsible for floodplain and tidal plain development through river morphology adjustment process. An alteration of one driver causes a series of alterations. In general, avulsion of the Brahmaputra River, tectonic activities (like 1950 Assam earthquake, subsidence), deltaic subsidence, and human interventions, along with delta progradation are the main drivers which have influenced the overall river characteristics of Bangladesh in different scale. A list of main drivers in different regions is given in the following **Table 6.1**.

Table 6.1: Drivers in different region of Bangladesh

Region	Drivers
North-West	➢ Human intervention: Teesta Barrage in India, Teesta Barrage in Bangladesh, groundwater abstraction

Region	Drivers
	➢ Teesta avulsion/shifting ➢ Brahmaputra avulsion and westward migration of the Brahmaputra
North-Central	➢ Brahmaputra avulsion ➢ Changes of flow regime in distributaries ➢ Human intervention: Unplanned settlement, industrialization along the distributary rivers in this region, Ground water extraction
North-East	➢ Tectonic subsidence ➢ Brahmaputra avulsion
South-East	➢ Tectonic uplifting, i.e. up folding, delta progradation
South-West and South-Central	➢ Ganges shifting to the east ➢ Brahmaputra avulsion ➢ Human intervention: dry season flow driversion, coastal polders ➢ Deltaic subsidence ➢ Delta progradation

Upstream human intervention and natural events, like the Teesta avulsion or shifting due to heavy rainfall in 1787, have profound impact on the river system changes and development in the North-West Region. The Teesta River is an alluvial fan river that follows sequential avulsion through different courses. The Teesta River which was a contributory river of the Ganges River was flowing along the course of the present the Atrai River. It avulsed to the east and merged with the then Brahmaputra River in late 18th century. During the last few decades, there were a number of human interventions such as the Teesta Barrage in India (in 1985) and in Bangladesh (in 1995), which have severe consequences on the availability of water during dry season. In North-West Region, intensive agriculture is being practiced, especially boro crops, for which intensive irrigation is required. On the otherhand, westward migration of right bank of the Jamuna River since 1830 was about 8 km, which caused the net losing of about 2,000 km^2 floodplain. Every year, several thousand floodplain dwellers become landless and homeless due to the high rate of riverbank erosion along the right bank. Moreover, erosion often breaches flood embankment causing widespread flooding in the adjacent floodplain.

The Jamuna avulsion and tectonic uplifting of the Madhupur Tract are the main drivers in the North-Central region. Unplanned urban area and industries development, development of road networks and huge abstraction of groundwater for the city dwellers are the human intervention in this region. Since the early nineteenth centuary, sources of water and sediment in this region have been shifted from the Old Brahmaputra River to the present Jamuna River, which caused the changes of the flow and sediment regimes of all distributaries.

Mainly due to recent human interventions in the rivers and floodplain, disconnection of the distributaries with the Jamuna and industrial effluent to the river have caused the water quality to deteriorate alarmingly. Intensive industrial development along the both side of the distributaries in this region has aggravated the condition.

Avulsion of the Brahmaputra and higher tectonic subsidence rate along the Garo Hills are the main drivers in the North-East Region. When Brahmaputra was flowing along the eastern boundary of the Madhupur Tract, the sediment supply could counterbalance the sediment deficiency due to subsidence. After the complete avulsion, the Surma and the Kushiyara rivers and some alluvial fan rivers are the main rivers in this region. But the sediment supplies by these rivers are not sufficient to compensate the subsidence rate. Hence, subsidence has become the governing process in this system. The subsidence rate is higher in the northern part of the Sylhet Basin might have caused the northward avulsion of the main rivers of this region. Evolution processes of the rivers after avulsion in a subsiding basin differs significantly (CEGIS, 2011) than any other palces. Rate of riverbank erosion and frequency of avulsion increases as the river enters into the subsiding Sylhet Basin.

Major physiographic-unit of this region is the Old Meghna Estuarine Plain (Figure 2.7) and there is almost no elevation diferecne in northsouth direction along the western margin. Elevation of central east part is higher than other location due to the presence of the Comilla Fold. The major constraints of drainage congestion in the south Comilla and north Noakhali would be due to the folds and deltaic accretion at higher elevation than adjacent forgoing plains.

Continuous shifting of the Ganges River from the west to the east is the main driver in the South-West and South-Central regions. Avulsion of the Brahmaputra has triggered the Ganges shifting process to the eastern boundary of the delta system. Reducing fluvial input to the South-West region due to shifting of the Ganges and its major distributaries has made the moribund delta, where net erosion is governing process.

The characteristics of the river system are most significant to the delta progradation process. In addition, human interventions for diverting water (dam, barrage) and social development (coastal polders, road network development) are also the cause of few major sufferings in this region. The construction of flood embankment and polders in the tidal plains has restricted the flood plain and tidal plain sedimentation, resulting in river bed sedimentation. Presently, the delta is prograding toward the sea in the Meghna Estuary, which is a tide dominated delta. Vertical accretion in the delta development is also active through the tide in the tidal plain. Huge sediment generated by Assam earthquake in 1950 is believed to have significant influence on the delta development rate more rapidly.

6.2. Climate Change as Future Driver

There is no comprehensive research to assess the impacts of climate change on the rivers, delta area and coastal morphology of Bangladesh, which may have profound effects on the future development of the country. CEGIS (2010) carried out a study funded by Asian Development Bank (ADB), to assess the impact of climate change on the morphological processes of the main rivers and the Meghna estuary. In this section few key and relevant findings of the CEGIS (2010) study and recent development of knowledge on the responses of the river to the climate change have been presented.

Temperature is the main driver of climate change which influences precipitation, river flow and sea level rise. These changes ultimately have impact on the geomorphology of the rivers through flooding, inundation, avulsion, salinity intrusion and disasters like flood, storm surge and cyclone.

The morphological responses of the Bengal Delta to the climate change will mainly be dominated by the main river system of Bangladesh, namely the Jamuna, Ganges and Padma Rivers and also the Lower Meghna River. In response to the sea level rise, the river will start adjust from its downstream base level (i.e. the Bay), while on the otherhand, due to climate change the rivers will adjust with its dimensions with the increase flooding almost simultaneouly.

Assessment on Discharge

There are large variations in the results predicted by using different Global Climate Change Models. Based on the model results, (Mirza, Warrick, Ericksen, & Kenny, 2001) mentioned that the probability of increase in flood discharge due to rise of global temperature in the Brahmaputra is less than that of the Ganges and the Meghna rivers. Mirza (Mirza & Ahmed Q., 2005) developed an empirical model relating the increase in precipitation in the Ganges and the Brahmaputra basins with the changes in mean annual discharge. It was shown that for different GCM model results, the probable maximum change in precipitation in the Ganges and the Brahmaputra basins for 2^0C increase in temperature may be 13% and 10.2%, respectively. This increase in the precipitation will result in changes in the mean annual discharge of the rivers by 21.1% and 6.4%, respectively. Recently, the Institute of

Water Modelling (IWM, 2008) undertook a study of the impacts of climate change on monsoon flooding in Bangladesh assuming a 13% increase in precipitation over the Ganges-Brahmaputra-Meghna (GBM) basins under the A1F1 emissions scenario and found a corresponding 22% increase in the peak discharge of the Ganges at Hardinge Bridge.

Table 6.2: Estimated average changes of percentage in discharge by 2050 based on 5 GCM X 2 SRES model experiments (Source: Winston, 2010)

Month	Brahmaputra	Ganges	Meghna
May	17.4	11.8	12.3
June	10.9	16.7	7.7
July	6.9	15.0	3.6
August	9.5	12.0	7.8
September	9.7	12.5	5.9

Assessment on Flooding

Two types of flooding have been associated with the effect of climate change in Bangladesh. Sea Level Rise (SLR) and its propagation in the coastal zone will increase the extent of tidal flooding. Other than this, changes in monsoon rainfall will increase the volume of flood discharge in the river system that will ultimately result in an increase in the flooded area.

Referring to (Hardy, 1992), Choudhury (1997) mentioned that 1 m SLR would cause inundation of 17% of the total area of Bangladesh. IPCC (2001) also mentioned about 21% of total land (30,000 km^2) inundation due to SLR of 1 m. The findings of recent studies are however, different. WARPO (2005) shows that in the year 2100, about 11% area (4,107 km^2) of the coastal zone (about 3% of the total area of Bangladesh) will be inundated at 88 cm SLR in addition to the inundated area in the year 2000 under the same amount of upstream flows. The IWM and CEGIS (2007a) have assessed the inundation in the coastal region of Bangladesh for 62 cm SLR and have concluded that increased rainfall in the next 100 years would cause 16% of additional inundation equivalent to an area of 5,500 km^2. The assessment of flood inundation was based on the numerical simulation considering no changes in river bathymetry, floodplain and tidal plain topography. With the same physical setting, recently, (Winston, 2010) projected additional flooding due to SLR and increased discharge in the rivers using numerical modellling. They mentioned that the flooded area in the Ganges and Jamuna floodplain will be increased at varying rates in different months for different regions. Flooding would be increased by about 10% by August 2050 in the Ganges and Jamuna floodplains. CEGIS (2010) suggested that annual flood discharge in the main rivers will be increased gradually due to climate change. The river morphology would be adjusted with the increased flood discharge. Recent studies suggest that unless the tidal plain is empoldered, it has the potential to adjust with the increased sea level, if sediments are available.

Regional Scenarios

Climate change will have distinguished impacts in river management sector at different regions of Bangladesh. Sea level rise, change in temperature and rainfall will have profound impact on river characteristics as they influence the discharge, sediment load and planform of the rivers.

In North-West region the existing water scarcity may be intensified as the effect of climate change. There will be longer dry season and shorter wet season and discharge will increase only in the wet season. On the other hand in North-East region the inundation level and extent will be increased as the effect of sea level rise. The subsiding rate also may increase depending on the sediment supply. In South-West and South-Central region, the wet season discharge will increase significantly. The sediment input may increase with increasing rainfall whereas establishment of dams and afforestation in the upstream reduce the sediment supply. Moreover, the poldering effect may be intensified as the effect of climate change. It would be more expensive to deal with the drainage problem due to sea level rise and lowering of polder areas. Additionally, climate change may greatly influence the delta shifting process as well as the river avulsion as it is related to sediment supply. In South-East region, the drainage congestion may be exaggerated as the effect of climate change because the accreted areas will be higher for higher mean sea level. Moreover, the flooding intensity may also increase in the north western side of this region.

6.3. Interlinking with other Thematic Studies

Integration among different thematic studies is an important aspect for long term development and planning under the Delta Plan (**Figure 6.1**). Because, a particular study can be linked to many other studies and activities under different studies are influenced by other. The River Management study has close linkage with many other studies and thus, the plans under this study should consider the interactions with others.

Figure 6.1: Linkage with other studies

Regional Cooperation

River management activities beyond borders influence the river system of Bangladesh eminently as we have many large trans-boundary rivers. Thus, the state of regional cooperation will greatly influence the river management sector.

Agriculture and Food Security

The agriculture sector is dependent on the availability of irrigation water and surface water irrigation is interrelated with the river management aspects. Thus, river management plans and projects should consider the prospect of food security.

Fisheries

River management structures have significant impact on the development of fisheries. These structures change flow direction, velocity and often disrupt the floodplain connectivity. Thus, river management activities should maintain adequate provisions so that the fish production and breeding are not affected in great extent.

Ecological Settings and Biodiversity

River management activities like structures influence the ecological setting and biodiversity of the surrounding catchment. For example, flood embankments impede the floodplain sedimentation process and thus, change the ecological setting and biodiversity to some extent.

Environmental Pollution

River management activities have impact on the river water pollution. Sometimes water pollution can be controlled by flow augmentation through dredging. On the other hand industrialization on the reclaimed land along the river can intensify the pollution of river water.

Land Resource and Population Management

There is ample opportunity of land reclamation along some large rivers of this country under river management sector. Land resource and population management are interrelated to river management sector in this regard.

Climate Change

Climate change may affect the fluvial system of Bangladesh through sea level rise, change in rainfall pattern, and change in temperature and sediment yield. Thus, the river discharge, planform and response of the river training structures are closely linked to the aspect of climate change.

Disaster Management

Bangladesh is mainly vulnerable to the river related disasters like flood, cyclone, erosion etc. Thus, disaster management activities have to be taken in integration with the river management sector.

Coastal Development

The development of the coastal area is related to the river management issues of that zone. Because river management considers salinity, polder and subsidence issues of the coastal zone which are important for the development of the coastal area. Availability of sediment from the upstream catchment would also be important for the erosion and accretion in the coastal areas. Potentials of adjustment of the tidal plain with sea level rise depends on the availability of the sediment as well

Socio-economic

The socio economic condition of Bangladesh can be greatly developed by proper river management through utilization of river resources. Thus, river management and socio-economic studies should be integrated properly.

Water Resources

Water resources features like surface and ground water availability, water use, flood, drought and the overall water resources development is closely related to the river management sector. Thus, integrated approach is required for developing long term plans under these studies.

6.4. Institutional Issues in River Management

Remarkable changes in river management in Bangladesh would be achievable following the NWPo (1999). WARPO is mandated for multi-sectoral involvement in the development project. Strengthening, empowering and engendered WARPO can made a real positive difference along with GoB's focus on participatory approach. In addition, coordination among the institutions under the same ministry or different ministries, which is a challenge for the government, would be sustainable for long term solution. However, international partners may play a significant role in this regard.

In the BWDB, riverwise solution is expected involving dedicated section for river manaegmnt. Block allocation under the framework DPPs would balance the consistency for adaptive construction and management. Ensuring stakeholder's participation in policy level and implementation level would achieve certain objective by the project.

Staff and institutional strengthening through capacity development would warrant a sustainable development for planning, designing and implementing.

6.5. Gender Issues in River Management

In the context of Bangladesh, gender issues are very vital and need to be addressed properly in river management and development plans. In this regard it is important to understand the difference in impacts that the river alterations can have on men and women and also the different roles and responsibilities that they play in using and managing river resources. It is observed that the women are the most vulnerable group during river-related disasters because of their distinct roles in family and society. Therefore, before taking up a project for sustainable management of river gender should be an important concern. The river management plan should involve gender needs and preferences, involvements and roles of men and women and a gender balanced approach. The guiding principle should be gender equity and equality that must be strengthened and reflected in management choices. There should be a gender policy in the river management plan supported by appropriate strategies and activities to accomplish that policy.

6.6. Long Term Challenges

The dynamic Bengal delta is going through an evolving process. Due to this, the delta is experiencing significant changes influencing the overall characteristics. Moreover, the effect of climate change has instigated prominent changes in this delta. Thus it has become very important to prepare a long term plan for this delta which will be adaptable with changing conditions and advancement in science and technology. But preparing a sustainable and adaptable long term plan is very challenging due to uncertainties in natural and social development. In Bangladesh, there will be major challenges regarding following issues during preparation of Delta Plan in river management sector. A stakeholders consultation meeting attended by experts in the related sectors was arranged to discuss regarding the challenges and knowledge gaps. The detail of this consultation meeting is presented in Annex A.

Develop a Vision

It has become very important to develop a vision for river management in Bangladesh. The vision should be based on future scenario to fulfill our future expectation from the river system. The vision should reflect the ultimate future perception of river system so that all the plans and strategies can be developed in order to achieve that vision. But fixing a vision will be very challenging as an integrated and optimized approach has to be maintained and there are enormous uncertainties regarding different issues.

Optimum Utilization

Bangladesh is highly blessed with enormous water resources. The river system of this country can facilitate in various sectors like water supply, navigation, fisheries, agriculture etc. Proper river management should ensure utilization of these resources through integrated approach. It is a great challenge for the decision makers to generate the river management plans in optimum way for optimizing utilization of resources in various sectors.

Connectivity of the River System

Maintaining the connectivity of the river system is important for ensuring floodplain sedimentation and providing river resources to the people of different areas through distributaries. In Bangladesh, off take sedimentation is a commonly observed process scenario for many distributaries mainly due to high sediment input from upstream. Moreover, human intervention occurs at the local level which affects the flow to the downstream. These phenomena significantly impede the flow of the rivers and thus, the floodplain sedimentation process is affected. Maintaining river connectivity is a great challenge as various factors are related to it including activities beyond the border, natural events and local activities.

Climate Change

The effect of climate change on the river systems of Bangladesh is a very critical issue as there is lot of uncertainties regarding this. Moreover, adequate data and information are not available regarding this issue and the extent of the impact is also uncertain. As a result, facing the effects of climate change on the river systems will be immensely challenging which is significant for river management.

Upstream Intervention beyond Borders

The tendency of constructing dams and regulators is intensifying day by day. Thus, the influence of upstream intervention on the river systems of this delta will increase in future. Assessing the impacts will be challenging due to lack of trans-boundary co-operation and data unavailability.

6.7. Regional Challenges

6.7.1. North- West

Controlling groundwater mining will be a challenging issue for this region, especially in the Barind Tract. Extensive groundwater extraction is occurring in this area for drinking water and other purposes. But groundwater recharge is not sufficient due to less soil permeability and high slope. Thus, groundwater level is decreasing day by day. Moreover, maintaining connectivity of river system and also between floodplain and rivers are significant challenges for this region. Maintaining the connectivity between rivers and floodplain is important for floodplain sedimentation and use of other river resources. But maintaining connectivity through control flooding will be a great challenge. Controlling upstream intervention in international and local level will be another challenge for this region.

6.7.2. North- Central

Water quality has deteriorated significantly in this region. Improving the water quality will be very challenging as industrial development and river encroachment is increasing. Moreover, sedimentation has occurred in the off-take of many important rivers and they have become morphologically inactive. This phenomenon has exaggerated water quality deterioration. It would be challenging to maintain regulated flow which can facilitate in improving water quality and at the same time will not make the banks of the rivers erosion prone.

6.7.3. North- East

Proper sediment management is the most important issue for this region. Sediment is needed for compensating high subsidence rate. Thus maintaining proper sediment balance will be very challenging as it is required to compensate the high rate of subsidence especially in the Sylhet Basin. Additionally, the topography of this region is unique and the much needed studies that deals with the challenging issue of sediment management of this region are not adequete. It is likely that this basin area is going to be treamendously affected by sea level rise and there might have increased unundation depth in future. It would be a great challenge to devise proper landuse in such worse physical development. South-West and South-Central

The southern part of this region is severely suffering from lack of fresh water flow from upstream. Thus, maintaining fresh water flow will be a challenge for this region. Another challenge will be to develop comprehensive planning for rivers east of the Baleshwar River as these rivers are becoming larger and morphologically more active. In addition, sediment management in polder areas have become a critical issue. It is required to develop a sediment intrusion process for the polder areas which will be technically very challenging.

6.7.4. South-East

In the South-East region, the main challenge will be to deal with drainage congestion. Because the southern part of this region has become elevated due to tidal amplification.

6.8. Knowledge Gaps

There is a lack of knowledge and information regarding river systems management which have made the long term planning very challenging. There are following knowledge gaps about the overall river system of Bangladesh:

- How to train the large rivers for optimum utilization of river resources in a sustainable way through following activities
    - Land Reclamation
    - Erosion protection
    - Enhancement of navigability
- River responses to the climate change
- Response of the delta to the climate change and sea level rise
- How to make balance between economic development and sustainability of the delta in times of climate change

Moreover, we have lack of sediment data, lack of information and have to face uncertainty regarding upstream intervention which intensifies the knowledge gaps.

There are also some knowledge gaps about the regional issues which include:

- Sinking of the Sylhet Basin
- Introducing sediment into the tidal plain
- Facing the drainage congestion in the context of climate change
- Maintaining controlled flooding in some areas for floodplain sedimentation

6.9. Comments on Sixth Five Year Plan (SFYP)

In the SFYP, river dredging as a means of river management has been given proper emphasis in addition to flood control, drainage and irrigation projects. Besides river dredging, some other aspects of river management are also set as specific objectives of the water sector, namely, protection of river bank erosion, land reclamation and regional and international cooperation for management of trans-boundary rivers. Strengthening and capacity building of water resources institutions in the various fields of river management is also set as an objective of the water sector. Although land reclamation is viewed as a priority issue as Bangladesh is a land hungry country, and is set as an objective of the water sector, there is no special reference made for land reclamation through river management.

River dredging is planned to be carried out in a systematic and comprehensive way together with river bank protection for smooth passage of flood flow of the river system. Implementation of major interventions, like the Ganges Barrage and associated works, have been set as a strategy to cope up with dry season water shortage and salinity intrusion problems in the South-West region. In the SFYP, basin-wide water resources development initiative is deemed as a strategy for long-term management of water resources under normal and emergency conditions of flood, drought and water pollution. Such a development initiative is also relevant to sustainable river management. Also, strategies like addressing the issues of climate change, land reclamation and public private partnership have complete relevance to river management.

6.10. Recommended Projects for Seventh Five Year Plan

The following projects are recommended for the Seventh Five Year Plan.

1. Preparing master plan for managing the main rivers of Bangladesh

In the past, various bank protections, dredging, flood control and other river management projects were undertaken mainly to protect important cities, towns, growth centers and public and private establishments and to ensure navigation. But there is lack of intregated approach and proper planning which impedes successful implementation and functioning of these projects. There are instances that bank protection works have aggravated the erosion situation in the downstream. On the other hand, occurrence of breach in the embankment has turned a manageable flood into a catastrophic one. Different agencies have intervened in the rivers and there has been lack of co-ordination among these agencies.

Lesson learnt from past experience of managing the rivers, particularly the main rivers of Bangladesh, is that a holistic and integrated approach is needed for sustainable management of the main rivers. Thus, we should prepare a master plan for the major rivers of our country which will include an intregated approach for managing the rivers so that optimum use of river resources can be ensured.

2. Pilot project for land reclamation in the Jamuna River

The Jamuna has widened from length averaged 8km to 12km since the early 1970s. The river now occupies much larger space than that it needs to convey the discharge and sediment load imposed on it. The idea of Jamuna river channelization and reclamation and development of land thereby, is in line with government policy. However, channelization of the whole length of the 240km long, the Jamuna River within Bangladesh is a massive human intervention that involves huge cost and also addressing of a number of issues. Therefore, a pilot project in this regard may be undertaken to assess the opportunity of land reclamation. The planning, design and implementation of the pilot project should be supported by hydraulic and morphological and relevant impact assessment studies.

3. Pilot project for allowing regulated sediment intrusion in polder areas

The polder areas in the coastal zone are highly vulnerable to subsidence and sea level rise. These areas receive little or no sediment from outside due to construction of embankments for preventing flooding and salt water intrusion. As a result, uncompensated subsidence is causing water logging and drainage problems. In order to address this issue, allowing regulated sediment entry into the polder areas may be considered. Prior to formulation of a project, pilot project can be taken at least for two polder areas: one in the South-West region and the other in South-Central region. The planning, design and implementation of the pilot projects should be supported by tidal sediment management studies together with during and post-implementation monitoring.

4. Study to understand the future development of the Sylhet Basin

Apparently, the Sylhet Basin is said to be going through a sinking process. It is needed to undertake a study project to evaluate the probable devlopment of the Sylhet Basin after few decades. It will facilitate in developing a long term plan for the basin area.

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BASELINE STUDY: 03

Water Resources

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Executive Summary: Study 03

This report concerns the baseline study on water resources, comprising its climate and physical setting, both surface and groundwater resources and both quality and quantity. It describes existing problems, developments and (government) plans for water resources. It facilitates the identification of challenges and opportunities for the BDP 2100 and identifies (additional) (no-regret) measures and strategies. As part of the baseline study, two expert consultation workshops and Delta Ateliers were held, focussing on drivers, pressures and impacts as well as opportunities for future development of water resources in the country.

Bangladesh is located in the delta of the Ganges-Brahmaputra-Meghna river system. Totalling approximately 24,000 kilometres, the country is traversed by a vast network of huge rivers, their tributaries and distributaries, mountain streams, winding seasonal creeks and canals. Some 405 rivers crisscross the country, of which 57 are trans-boundary. Bangladesh is characterised by a sub-humid to humid monsoon climate, with relatively cold, dry winters and warm, humid summers. Approximately 80% of rainfall is concentrated in the five monsoon months, with an average annual rainfall of 2666 mm, ranging between 1100 mm in the extreme West of the country to some 5680 mm in the North-east. The mean annual temperature is about 25° C, with extremes of 4° C and 43° C. Humidity ranges between 60% in the dry season and 98% during the monsoon (FAO Aquastat, 2011).

The water resources available to Bangladesh consist of both internally generated surface water resources – though rainfall and runoff and trans-boundary inflows, and groundwater. According to FAO (2013), on an annual basis, the total renewable water resources amount to approximately 1211 (bcm). Of these, 1190 bcm are surface water and 21 bcm are groundwater resources. Internal renewable water resources (those generated inside the country) are estimated at 105 bcm, of which 84 bcm originate from surface- and 21 bcm from groundwater. Externally renewable water resources total 1106 bcm, of which 0.03 bcm from groundwater and the remainder from trans-boundary river flows.

Water resource is the key to the country's sustainable development. The National Sustainable Development Strategy (NSDS), published by Government in 2013, (GED, 2013), identifies the following five priority development sectors for the country: Agriculture, Industry, Energy, Transport and Human Resource Development.

Water resources are particularly vital for the *Agriculture sector*, which includes the crop sector, livestock, fisheries and forestry sub-sectors. Agriculture provides employment to approximately 70% of the population and contributes some 19.5% to the National GDP. Fish and fishery products are the country's third largest export commodity contributing 5.1% of its exchange earnings (FAO), 4.91percent of its GDP and provide over 60% of the national animal protein consumption (DoF). *Water availability and habitat quality*, especially in the dry season, and *water quality, notably salinity*, as well as *flooding* and *drainage congestion*, are key water resource issues for the Agriculture sector.

Water resources are also important for the *Transport* sector. According to Mishra et al (2012), the Inland Water Transport (IWT) sub-sector, supports the livelihoods of some 6.4 million people and contributes 30% of overall freight transport output and 20% of passenger travel. The IWT sector is growing rapidly, with cargo traffic increasing from 20 to 30 million tons annually from 1994 to 2005. 12,3% of the rural population or 50% of all rural households have access to water transport (World Bank, 2007). *Navigability of the waterways* and *port development* are key issues for the IWT sub-sector.

The importance of water resources for the *Industry* sector, an important engine for the countries growth the last 10 to 20 years, is growing rapidly. Whereas water demand is still low compared to the Agriculture sector, industrial use is expected to grow by 440% by 2050. Water resources are particularly important for the textile and leather industries, both in terms of consumptive needs and in view of the pollution *pressures* caused. The textile sector accounts for more than 85% of all export earnings, more than 10% of GDP and provides direct employment to more than four million workers. *Water quality* and *reliability of supplies* are important water resource issues for the Industry sector.

Human Resource Development is strongly affected by the availability and quality of water resources and a safe sanitation system, with particular poverty, gender and health dimensions. Key issues include *arsenic* in groundwater and the *declining water table* in areas such as Dhaka and the Barind, the occurrence of *waterborne diseases* due to lacking sanitation services and the resultant *economic loss*, especially of poor and female headed households. Although not a large water user compared to the agriculture sector, the demand is expected to increase by 100% in 2050. Current use is in the order of 10% of total water use in the country.

The *surface water* resources available in Bangladesh include main and regional rivers and a vast network of wetlands. Some 1.2 bcm of surface water is available to the country, of which the main part is of trans-boundary origin. The surface water resources are not evenly distributed over the year, with about 80% of the total flow *occurring* during the monsoon period (between June and October).

Water quality is a growing concern for the country, with 32 Rivers and many of the wetlands at serious environmental risk due to pollution, encroachment, and disconnection between wetlands and the river system.

Groundwater is an important source of water for irrigation and (safe) drinking water and – to a growing extent – industrial purposes. Some 80% of irrigation originates from groundwater, particularly for the cultivation of Boro rice (FAO Aquastat, 2011), which has been an important driver for attaining food self-sufficiency in the last two decades. Key issues include arsenic pollution of shallow aquifers and intrusion of salt water. Industrial pollution, although not yet well known, is threatening groundwater quality in industrial zones. Due to intensive groundwater development, the groundwater table has gradually declined in the North-west and North-central regions and specifically in Dhaka, where groundwater accounts for 80% of all drinking water resources and where a decline up to 75 m has occurred. In these areas, evidence indicates that recharge does not keep up with abstraction.

Illustrative of Bangladesh's challenging climatic environment and position in the low-lying Delta of three major rivers, is the occurrence of droughts and floods occur About 20% of the country is flooded annually, during extreme events this can increase up to 60% or more. In the dry season, water availability can be a serious constraint with major droughts occurring on average once every three years.

Being a sub-humid to humid country, Bangladesh has not traditionally been well endowed with water resources. A quickly growing economy, and the potential risks associated with climate change and trans-boundary infrastructure development, requires the countries' water planners to undertake precise and comprehensive balancing of water supply and future demand. Future water demand depends to a large extent on the growth and characteristics of the agriculture sector, currently constituting some 90% of overall water demand. Industry and the Domestic sector are increasing however and an increased awareness exists of the in-stream demands for environmental needs and salinity control. Predictions vary depending on the scenarios and model assumptions used – both regarding socio-economic development, climate and agricultural growth - and this requires further analysis.

The GBM river system has the largest total sediment load in the world, derived principally from upstream areas. Coupled with a dynamic hydraulic regime, the main rivers are subject to active erosion and sedimentation processes. On average, some 6000 ha of river bank erosion occurs in the country on an annual basis, leading to the displacement of about 50000 people.

In response to a number of disastrous floods in the 1950's, the first master plan for water resource development was initiated in 1964. The plan envisaged the creation of 58 large flood protection and drainage projects. More flood control, drainage and irrigation schemes (FCDI) were developed after 1972, leading to a current total number of over 1270 FCDI schemes in the country, developed by BWDB and LGED and covering more than 6 million ha in the country. In addition, the country avails of 4 barrages across the rivers Teesta, Tangon, Buri-Teesta and Manu, which are used as diversion structures for (supplementary) irrigation. Irrigation development, accompanied with High Yielding Value crop development, particularly Boro rice, and making use of the abundant groundwater resources, has been spectacular in the country, leading to a total of more than 6 million ha of irrigation at present. As a result, the country is now self-sufficient in food, particularly in rice.

Challenges are natural- as well as man-made, including alternating floods and droughts, cyclones, expanding water needs of a growing population, large scale sedimentation and river bank erosion, rapid urbanisation and industrialisation, global warming and deforestation. An additional and growing challenge is the deterioration of surface and groundwater water quality, the decline of natural wetlands and water bodies and the maintenance of healthy aquatic ecosystems. Climate change, the expected upstream development and abstraction of water and the lack of a sustainable financing of water resource infrastructure operation & maintenance further exacerbate these challenges. Critical challenges include:

i) Decline of wetlands and disconnection of these with the regional and main river system, with a negative impact on water quality, the quality of capture fish habitats ad ecology and increases the pressure on ecologically sensitive areas.
ii) Water demand management. The SW region and selected parts of the NC and NW regions are in deficit regarding their surface water resources and this will increase if current agriculture and domestic/industrial growth patterns continue to develop. This trend is presently leading to unsustainable groundwater use in selected areas of the North-west and North-central hydrological regions (including Dhaka area).
iii) Decreased dry season flows and tidal flows in rivers in the South-west of the country, due to a decrease in dry-season flows of the Ganges River in combination with the obstruction of the drainage paths due to FCD construction. Water-logging and increased salinity in the coastal area are key impacts.
iv) Deteriorating surface and groundwater quality caused by untreated effluent disposal by industries and domestic sources. Water quality worsens severely and some 32 rivers are considered at risk of severe environmental degradation.

v) Flood risks caused by riverine and coastal floods related to extreme rainfall, cyclones and storms. With economic growth and urbanisation, flood risks are expected to increase notably in the near future, also of critical infrastructure such as electricity supply and IT.
vi) Water-logging in urban and rural areas, caused by a number of factors, including unplanned and ineffective drainage infrastructure provision in local infrastructure, encroachment on wetlands in urban and rural areas and the hampering of tidal flows in the coastal area.
vii) Ensuring adequate focus on gender aspects in planning and operational water management, given the important role of women in providing drinking water and food security for their families and their own vulnerability to water hazards.
viii) The annual rate of river bank erosion is about 6000 ha per year. As a result, embankments can be undermined and farmers, especially those living at the Char lands, risk losing their land. The annual displacement is estimated at 50000 people.

ix) River siltation, affecting the desired water depths for navigation, discharge distribution between rivers as well as freshwater supply to dependant areas.

There is a clear need to develop integrated water quality and quantity management, to maintain the capacity of the eco-system to deliver its services for the various economic sectors, maintain acceptable levels of flood risk and promote efficient and socially responsible water use. To face these challenges, integrated planning, knowledge development and innovation, sound delineation and cooperation between the public and private sectors and improved governance and institutional development are the keys.

Water resource planning and development is guided by the principles laid down in the National Water Policy and National Water Management Plan, both spearheaded by the Ministry of Water Resources. Both documents incorporate and refer to other policies, and are taken further in the new (2013) Water Act; thus laying the basis for IWRM in the country. The main Government organizations involved in the water sector include 6 ministries and their implementing agencies: the Ministry of Water Resources (including the Bangladesh Water Development Board or BWDB and the Water Resources Planning Organization or WARPO), the Ministry of Local Government, Rural Development and Cooperatives (including LGED), Ministry of Agriculture, Ministry of Fisheries and Livestock, Ministry of Land and the Ministry of Environment and Forests. Other organizations include the National Water Resources Council (NWRC), of which – as laid down in the new Water Act - WARPO is the executive secretariat, the Planning Commission and General Economics Division (GED) and regional, national and international NGOs. A particular strength lies in the presence of dedicated water resource planning and research organisations such as Universities, CEGIS and IWM, many of which are involved in international exchange and research and consultancy projects.

A gap exists however between the adoption of the principles of IWRM and sustainable development and actual implementation. Key issues include:

i) The need for reliable and up to date water budgets for each Region and Catchment, leading to Water Allocation Plans that include all key water related sectors.

ii) Securing O&M financing at local, regional and national level.

iii) Application and strengthening of the IWRM concept at catchment and sub-catchment level, based on reliable and up to date data and models, taking into consideration all IWRM aspects.

iv) Sustainable WMO model development, incorporate the different interests of water users and stakeholders at local and regional level

v) Implementation, monitoring and enforcement of regulations in both water quantity (surface and groundwater) and water quality.

Potential measures and strategies:

- In this Baseline Study, a first assessment is provided of potential measures and strategies for further development in the BDP with specific reference to water security. Both infrastructure and institutional measures and strategies are considered: *Enhanced water use efficiency and water productivity* through precision water management in Irrigation and FCDI areas, including advanced technologies. The public sector plays an enabling role (including both the water and agriculture sectors) and supports private sector parties in innovation and business development.

- *Integrated water resource management at (sub-) catchment level*, including the development of detailed water balances, (real-time) technologies and institutional arrangements that facilitate integrated water resource planning and operation. This strategy builds on the public sector, including organisations such as WARPO, BWDB and LGED but also creates space for private – Non-Government initiatives.
- *Water resource infrastructure and technology development*. Whereas this strategy is mostly a continuation of previous (FCDI) Water Resource, Water Supply and Water Treatment development strategies, innovation would be sought by considering integrated objectives (IWRM and Water Security) and by – from the onset – considering the future management, business development, cost recovery, operation and maintenance whilst designing and commissioning such development. Integrated assessments would be used (see below under *development of integrated modelling*) to prioritise the already identified infrastructure schemes in the NWMP and other Sector Plans and Strategies.
- Develop the potential for *Managed Aquifer Recharge* in the *Coastal area* and the *North-west/North-central* regions to augment fresh water supplies for households and communities in a sustainable manner. The Public sector, through DPHE, BWDB and the District Authorities would take the lead.
- *Design, test and replicate green adaptation strategies* that make use of and enhance natural bio-physical processes and serve multiple goals. They reduce flood risk, but also enhance ecological development
- Development of a social safety net to provide socio-economic security to vulnerable groups affected by floods. Especially the Public and NGO-sector, and possibly the Insurance sector, would take the lead in this strategy.
- Highly developed Early Warning Systems and Strategies for Floods and Droughts, including spatial planning that accounts for flood risk by using flood zonation and drought vulnerability maps and developing area-based flood and drought safety plans. A strong combination of locally tailor made and Public-Private partnerships would take the lead in this strategy.
- Further and accelerated development of integrated modelling and data collection/monitoring instruments, including full 2-D flood modelling, water quality and water demand modelling, open source applications, including Open Earth and Global Data, participatory monitoring and data collection and integrated meta-modelling (see also Chapter 5) to carry out integrated assessments of scenarios, strategies and measures at national, regional and local level, across all water related sectors. The Public Sector would enable Knowledge Institutions and Private Sector to take the lead in this strategy and ensure sharing of data. Specific innovation programs, will spearhead the development.
- *Public-private partnerships to manage (FCD) Irrigation schemes*, allowing for financial autonomy and providing incentives for technological improvement of water resource management in these areas. Typically, such a strategy would involve both Public and Private Partners, with the Public Sector focussing on its role in developing the enabling legal environment.

1. Introduction

1.1. Objectives of the Baseline Study on Water Resources

Thematic studies play an important role in the project. They provide the knowledge backbone of the Delta Plan and form the basis for the development of a Delta Vision (i.e. a vision on the development of a robust and productive water system in support of national socio-economic priorities) and the preparation of the Delta Decisions (i.e. on Water Resources Development, Policy and Regulation and Intuitional Capacities). The baseline studies are clustered into 8 main clusters of which Water Resources is one. The Water Resources cluster consists of the baseline studies water resources, river systems management and morphology, and coast and polder issues. Although the water resources baseline study is a separate study, there are close linkages with the themes on disaster risk management, river morphology, water supply and sanitation, agriculture and food security, climate change, environmental management, governance and regional cooperation, to name but the main linkages.

The objectives of the baseline are

1. To evaluate existing problems, developments and (government) plans for Water Resources
2. To facilitate the identification of challenges and opportunities for the BDP2100,and link these to building blocks for Delta Vision and development, as well as 7th 5-year plan;
3. To identify (additional) (no-regret) measures and strategies;
4. To inform the stakeholder analysis carried out in other baseline studies;
5. To support joint fact-finding, contributing to project ownership and partnership development;
6. To contribute to the creation of a common knowledge base;
7. To identify knowledge gaps and research needs;
8. To identify exemplary projects for implementation

1.2. Approach and Methods

The methods for the baseline study built on both joint fact finding by the study team and other baseline study teams and the use of existing reports, plans and model outputs. The following aspects are important (summarized from the Terms of Reference for the Baseline Study):

- Coherence with other Baseline Studies;
- Building on the existing structure – and models - of separate hydrological zones, as outlined in the 2001 National Water Management Plan (NWMP) and the National Water Resources Data Base (NWRD);
- Analysis of the natural and man-made hydrological system of the country including coverage of key economic sectors insofar as these are not covered by the other baseline studies;
- Close linkage with the Delta Ateliers/Hot Spot analysis for which the Baseline study would provide an important input;
- Identifying key tipping points and estimating when these would occur, based on the climate and socio-economic scenarios developed in the Climate Baseline Study;
- Examining expected future challenges based on selected future scenarios as developed under the Baseline Study on Climate Change. Typical changes with respect to water resources include: i) flows of major rivers; ii) climate variability; iii) surface water balances in the hydrological zones; iv) groundwater balances; v) water demands in agriculture, drinking water and industry.

1.3. Structure of the Report

After the introductory Chapter 1, which includes objectives of the baseline study, approach and methodology, the main theme of the baseline, the water resources starts. Chapter 2 describes the water resources in Bangladesh, both surface and groundwater, and the availability of both. Chapter 3 describes the water resources development, including flood control, drainage and irrigation; water use and demand, key challenges for floods and droughts. Water resources planning and organisational setup are described in Chapter 4. The chapter also describes the history of water resources planning and various plans in last decades, National Water Management Plan (NWMP), water resources management institutions, participatory water management, key issues and knowledge gaps. Chapter 5 narrates the outlook and future challenges including scenarios and drivers of change, potential impacts on water availability and quality, floods and river erosion; and potential for future development and promising strategies.

Bangladesh Delta Plan 2100 developed 19 baseline studies (plus 3 baseline later), and the study on water resources is one of them. As the Delta plan is basically water-centric, the water resources baseline has obvious relevance to other important topics, such as River Morphology, Disaster Management, Climate Change, Environment, Ecology, Agriculture, etc. In many places of the text, reference has been made to one or more other baseline studies.

2. Water Resources in Bangladesh

2.1. Introduction

Bangladesh; the low-lying delta of three great rivers

Bangladesh is located in the delta of the Ganges-Brahmaputra-Meghna river system (**Figure 2.1**). Totalling approximately 24 thousand kilometres (A.A. Rahman, S. Huq and G.R. Conway, 1990), the country is traversed by a vast network of huge rivers, their tributaries and distributaries, mountain streams, winding seasonal creeks and canals. Some 405 rivers crisscross the country, of which 57 are trans-boundary. Bangladesh is characterised by a sub-humid to humid monsoon climate, with relatively cold, dry winters and warm, humid summers. Approximately 80% of rainfall is concentrated in the five monsoon months. The *water resources* available to Bangladesh consist of both internally generated surface water resources – though rainfall and runoff, trans-boundary inflows and groundwater.

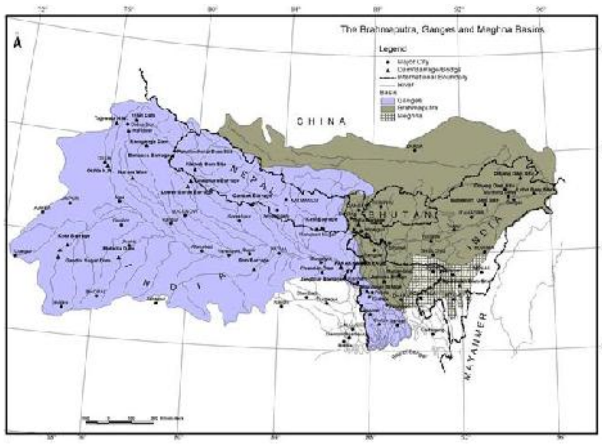

Figure 2.1 The Ganges, Brahmaputra and Meghna Basins (NWMP, 2004)

Surface water resources; internal and trans-boundary

The total catchment area of the three rivers is 1.72 million km^2 of which some 7% lies in Bangladesh (Joint River Commission, http://www.jrcb.gov.bd/). Annual cross-border river flows, entering the groundwater and river systems, are estimated to be 1260 bcm, of which the three main rivers contribute 981 km^3, 85% of which enters the country between June and October (Mac Kirby et al, 2014). Of the latter amount, some 54% is contributed by the Brahmaputra, 31% by the Ganges and nearly 14% by the tributaries of the (Upper) Meghna. 1% is contributed by other minor rivers of the Eastern Hills. Dry season flows are an estimated 148 bcm or 15% of the total annual river flows (Mac Kirby, 2014). Current water use (2011) is approximately 36 bcm per year (Mac Kirby, 2014).

Groundwater; a vital resource

Groundwater is an important source of water for irrigation and (safe) drinking water and – to a growing extent – industrial purposes. Some 80% of irrigation originates from groundwater, particularly for the cultivation of Boro rice (FAO Aquastat, 2011), which has been an important driver for attaining food self-sufficiency in the last two decades. Estimates of the total available amount of groundwater vary considerably. According to the Master Planning Organisation study of 1997 (MPO, 1997), some 21 bcm of groundwater resources is produced within the country, with an unknown but estimated important quantity of groundwater flowing into the country through horizontal flow paths from the Himalayas. Rajmohan and Parther (2014) suggest that the annual groundwater recharge is about 65 bcm whilst Hodgson (Regional Water Balance Study, CSIRO, 2014) suggests that the net recharge is about 28 bcm. An estimated 11% of rainfall is recharged to groundwater, with country-wide variations between 8% (for the Barind area) and 15% (Prof Chowdhury Sarwar Jahan, Presentation Delta Atelier Drought Prone Area, June 2015).

Water resources key to sustainable development

Water resources are key to the countries' sustainable development. The National Sustainable Development Strategy (NSDS), published by Government in 2013, (GED, 2010 – 2021), identifies the following *five priority development sectors* for the country: *Agriculture*, *Industry*, *Energy*, *Transport* and *Human Resource Development* (NSDS, p. xii and further).

Of these, water resources are particularly vital for the *Agriculture* sector, which includes the crop sector, livestock, fisheries and forestry sub-sectors. Agriculture provides employment to approximately 70% of the population and contributes some 19.5% to the National GDP (2004 – 2010, NSDS, 2013). Fish and fishery products are the country's third largest export commodity contributing 5.1% of its exchange earnings (FAO, 2011), 4,91percent of its GDP and provides 63% of the national animal protein consumption (DoF, 2003). An estimated 90% of the countries water resources are consumed by the agriculture sector. *Water availability and habitat quality*, especially in the dry season, and *water quality*, notably *salinity*, and *drainage congestion*, are key water resource issues for the Agriculture sector.

Water resources are also important for the *Transport* sector, although less so than for Agriculture. According to Mishra et al (2012), the Inland Water Transport (IWT) sub-sector, supports the livelihoods of some 6.4 million people and contributes 30% of overall freight transport output and 20% of passenger travel. A 2007 World Bank study (2007, quoted in: Mishra, D. K. et al, 2012), revealed that IWT has proved more accessible and cheaper than roads and railways and the poor people use the mode more. The same study shows that 12.3% of the rural population or 50% of all rural households have access to water transport. The IWT sector is growing rapidly, with cargo traffic increasing from 20 to 30 million tons annually from 1994 to 2005. *Navigability of the waterways* and *port development* are key issues for the IWT sub-sector. Bangladesh Inland Water Transport Network is shown in the following map, **Figure 2.2**.

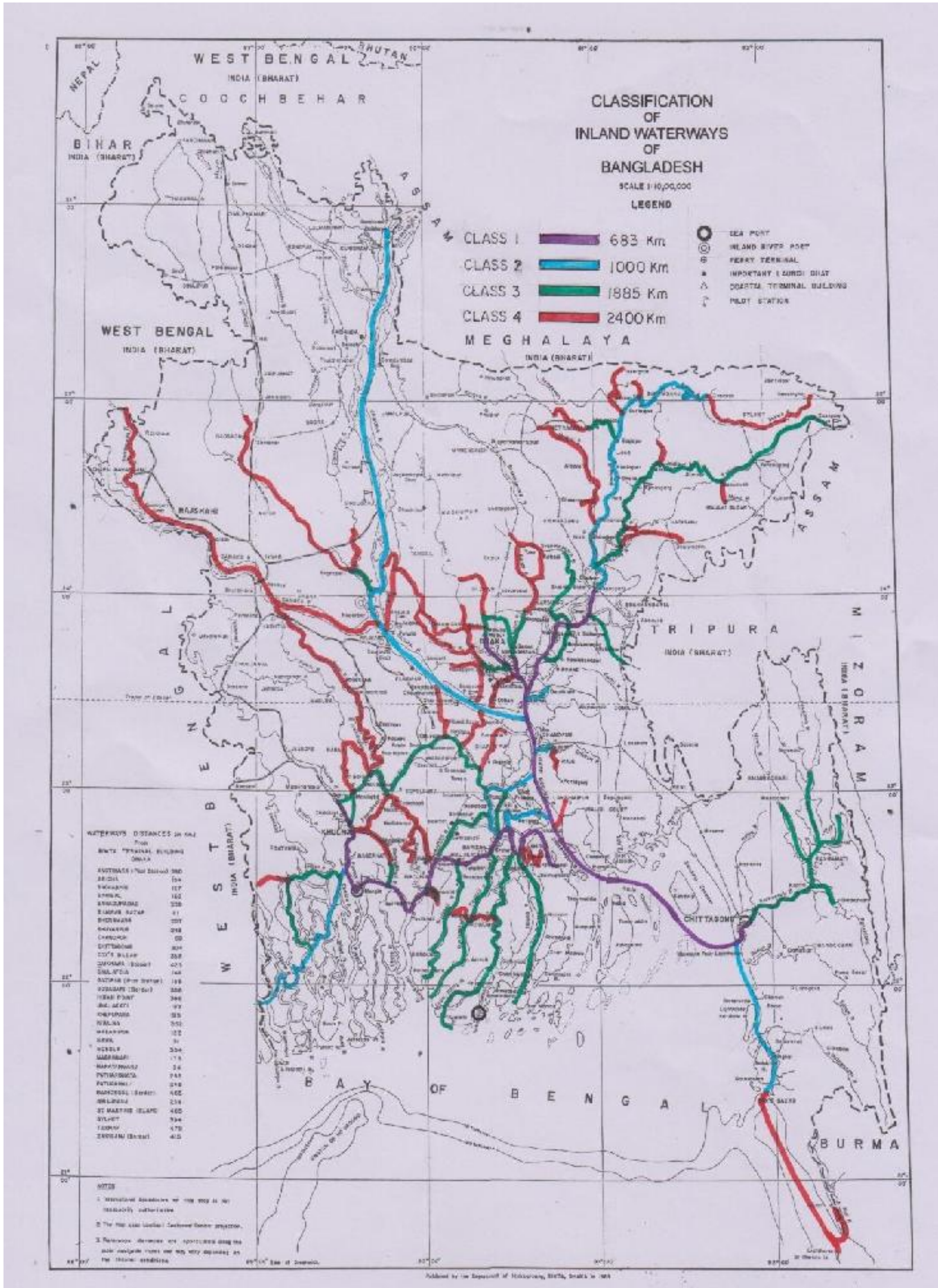

Figure 2.2: Inland Water Transport Network

The importance of water resources for the *Industry* sector, an important engine for the countries growth the last 10 to 20 years, is growing rapidly. Whereas water demand is still low compared to the Agriculture sector, at an estimated 0.08 bcm per year, industrial use is expected to grow by 440% to approximately 0.35 bcm (Mainudin, 2013) by 2050. Water resources are particularly important for the textile and leather industries, both in terms of consumptive needs and in view of the pollution pressures caused. The textile sector accounts for more than 85% of all export earnings, more than 10% of GDP and provides direct employment to more than four million workers. The leather industry, although smaller, still employs approximately 750000 workers and provides some USD 1 billion in export earnings annually. According to a recent study carried out by the Water Resources Group, the textile and leather industries predominantly use groundwater to meet their demand, mostly through unmetered self-supply. The same study predicts that, at anticipated textile growth rates, the demand from that sector will increase to 9500000 m^3 per day, or the equivalent of 17.6 million inhabitants (at an average consumption of 125 litres per person per day). *Water quality* and *reliability of supplies* are important water resource issues for the Industry sector.

Human Resource Development is also strongly affected by the availability and quality of water resources and a safe sanitation system, with particular poverty, gender and health dimensions. Key issues include *arsenic* in groundwater and the *declining water table* in key areas such as Dhaka and the Barind, the occurrence of waterborne *diseases* due to lacking sanitation services and the resultant *economic loss*, especially of poor and female headed households. Although not a large water user compared to the agriculture sector, the demand is expected to increase notably, by 100% in 2050. Current use is in the order of 2.7 bcm or some 10% of total water use in the country.

The only sector where water resources are not (yet) a main concern is the *Energy* sector. Being a low-lying delta, hydropower is not widely developed in the country, with the exception of Kaptai Reservoir in the South-east of the country. On the other hand, inland waterways are important for the transport of the (fossil) fuel resources. This picture may change in the foreseeable future, when *tidal energy*, particularly in the South-eastern part of the Meghna Estuary (where tidal ranges of 7 meters occur) becomes a viable economic option.

In summary; the saying *'water is life'* holds especially true for Bangladesh, with 4 out 5 of the countries' priority sectors depending on water resources for their sustainable development.

This chapter deals with the water resources available to Bangladesh. Both surface and groundwater resources are discussed, distinguishing between the resources generated in-country and trans-boundary flows, so crucial for the countries' future. After providing an overview of the water resources, water resource development is considered, focussing on the Flood Control, Drainage and Irrigation (FCDI) schemes that were development from the 60's onwards. Two key issues are highlighted in more detail: Drought and Floods. Key issues and knowledge gaps are summarised in the final section.

2.2. Hydrological Regions

Water Resource Planning within Bangladesh is carried out on the basis of 8 hydrological regions (**Figure 2.3**), as laid down in the National Water Policy (NWPo, Ministry of Water Resources, Government of Bangladesh, 1999): "*The intricate nature of drainage systems within the country requires that activity for planning and management of the nation's river systems is undertaken within the context of hydrological regions. The principal river systems create natural boundaries for these regions. The hilly areas of the East form another hydrological region*" (NWPo, 1999).

In defining hydrological regions the adopted principles were: (i) the entire country should be covered; (ii) the principal rivers and natural features *should* form boundaries; (iii) the principal rivers themselves form a region; and (iv) effective use should be made of previous studies. Eight regions have been defined: Northwest (NW), Northeast (NE), North-central (NC), Southeast (SE), South-central (SC), Southwest (SW), Eastern Hills (EH) and the main Rivers and Estuaries (RE).

The latter (RE) includes the active floodplains and char lands. Within each region, sub-regions and catchments are defined, forming the basis for detailed water resource planning. The RE region comprises the major rivers which, in terms of water resources, interact strongly with the other regions. For this purpose a set of seven extended hydrological regions (EHRs) has been defined as well, in which the RE region has been absorbed into other regions. An overview of key features for each region is provided below (**Table 2.1**).

Table 2.1 Features of the 8 Hydrological Regions (NWMP, 2004)

Hydrological Region (HR)	Gross Area (km^2)	Gross Area Extended (EHR)	Est. pop. 2011 (M.)	Est. pop. 2025 (M.)	Average Rainfall (mm)	Main Towns
South West (SW)	26,100	26,445	18.91	23.3	1,655	Khulna, Jessore
South Central (SC)	15,236	16,432	11.10	14.0	2,307	Barisal, Bhola
North West (NW)	31,607	33,974	33.94	42.2	1,739	Rajshahi, Pabna, Bogra
North Central (NC)	15,950	17,001	33.64	50.4	1,956	Dhaka, Gazipur, Tangail
North East (NE)	20,061	20,038	17.67	17.6	3,194	Sylhet, Sunamganj
South East (SE)	10,275	12,615	15.27	18.2	2,271	Chandpur, Comilla, Feni, Noakhali
Eastern Hills (EH)	19,910	21,065	10.12	15.3	2,445	Chittagong, Cox's Bazar
Rivers & Estuaries (RE)	8,431	na	na	na	2,318	
Total	147,5700		140.65	181	2,360	

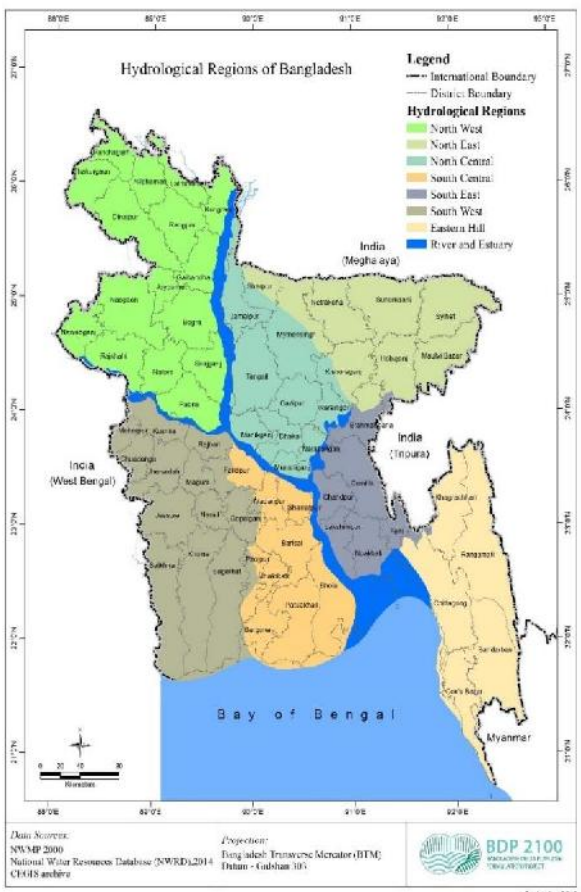

Figure 2.3: Bangladesh Hydrological Regions

Source: CEGIS, from NWRD, 2014

2.3. Climate

Bangladesh has a typical monsoon climate characterized by rain-bearing winds, moderately warm temperatures, and high humidity. It receives heavy rainfall, of which 80% occurs during the monsoon period, from late May to mid-October. Dependable rainfall (defined as rainfall that is exceeded four years out of five for any month varies between 1335 mm per annum in the North-west region to 2595 mm in the Northeast region (**Table 2.2**).

Table 2.2: Dependable rainfall by region (mm/month, NWMP, 2004)

Region	J	F	M	A	M	J	J	A	S	O	N	D	Total
SE	0	0	4	60	137	305	344	280	177	56	0	0	1,746
NW	0	0	0	20	111	194	278	173	171	35	0	0	1,335
NC	0	1	4	53	149	229	272	184	162	55	0	0	1,529
RE	0	0	1	40	132	292	354	274	192	56	0	0	1,810
SW	0	0	0	18	83	189	247	218	163	54	0	0	1,259
NE	0	1	21	128	267	415	433	335	274	78	0	0	2,595
SC	0	0	1	31	112	313	350	306	180	73	0	0	1,793
EH	0	0	0	37	110	367	407	282	156	69	1	0	1,733
B'desh	**0**	**0**	**4**	**45**	**134**	**276**	**327**	**246**	**183**	**58**	**0**	**0**	**1,725**

Note: Annual Dependable Rainfall is not the sum of the monthly values

Average annual total rainfall is further visualised below with rainfall data up to 2013 extracted from the National Water Resources Data Base (NWRD).

Mean annual minimum temperatures range from 10-12°C in January to 20-25°C in June to August, and mean monthly maximum temperatures range from 25-28°C in January to 32-35°C in June to August. The winter months constitute an ideal growing climate not only for Boro rice but a great variety of perennial and seasonal crops. An overview of the main climate features is presented in the figure below.

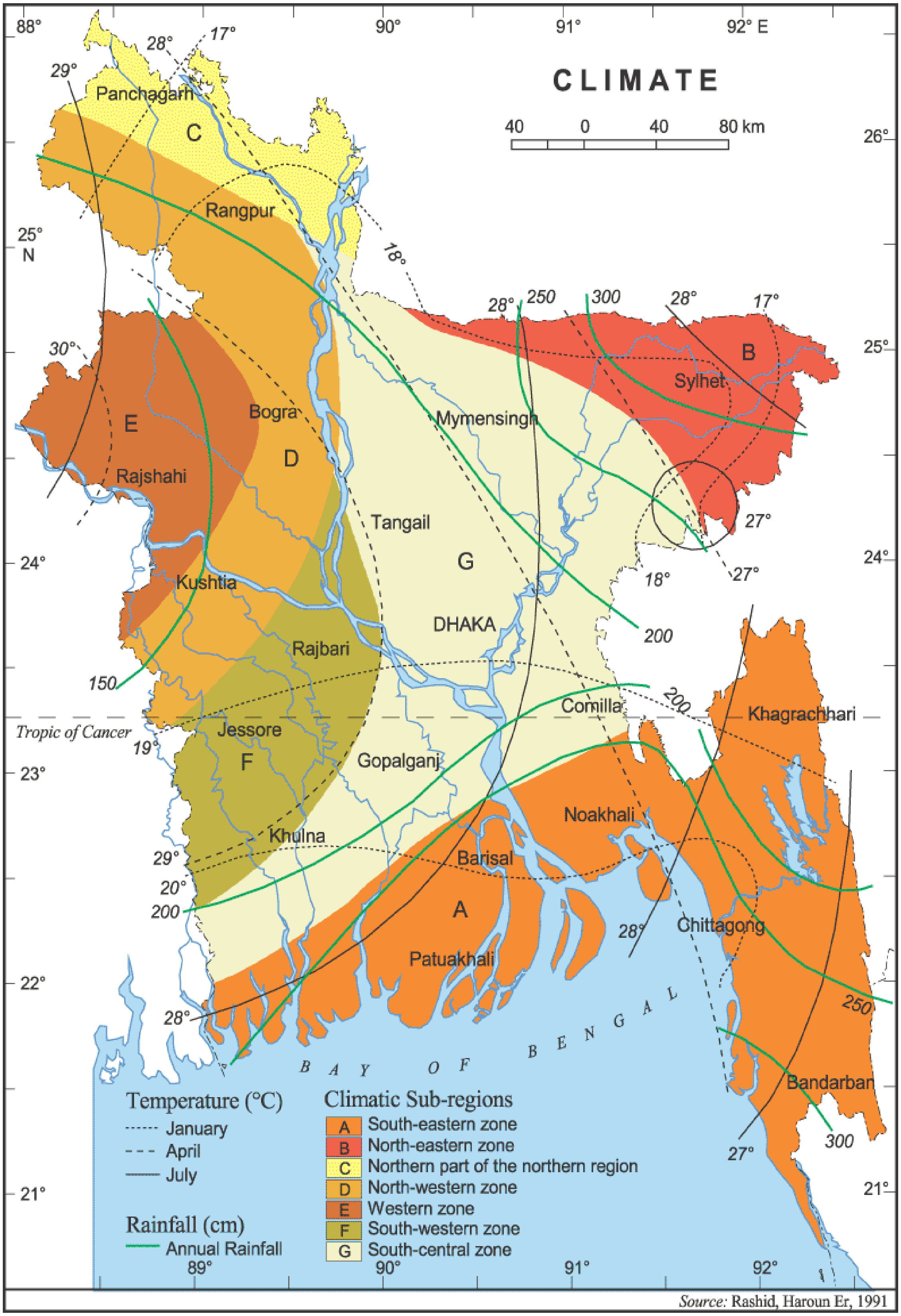

Figure 2.4: Main climatic features of Bangladesh

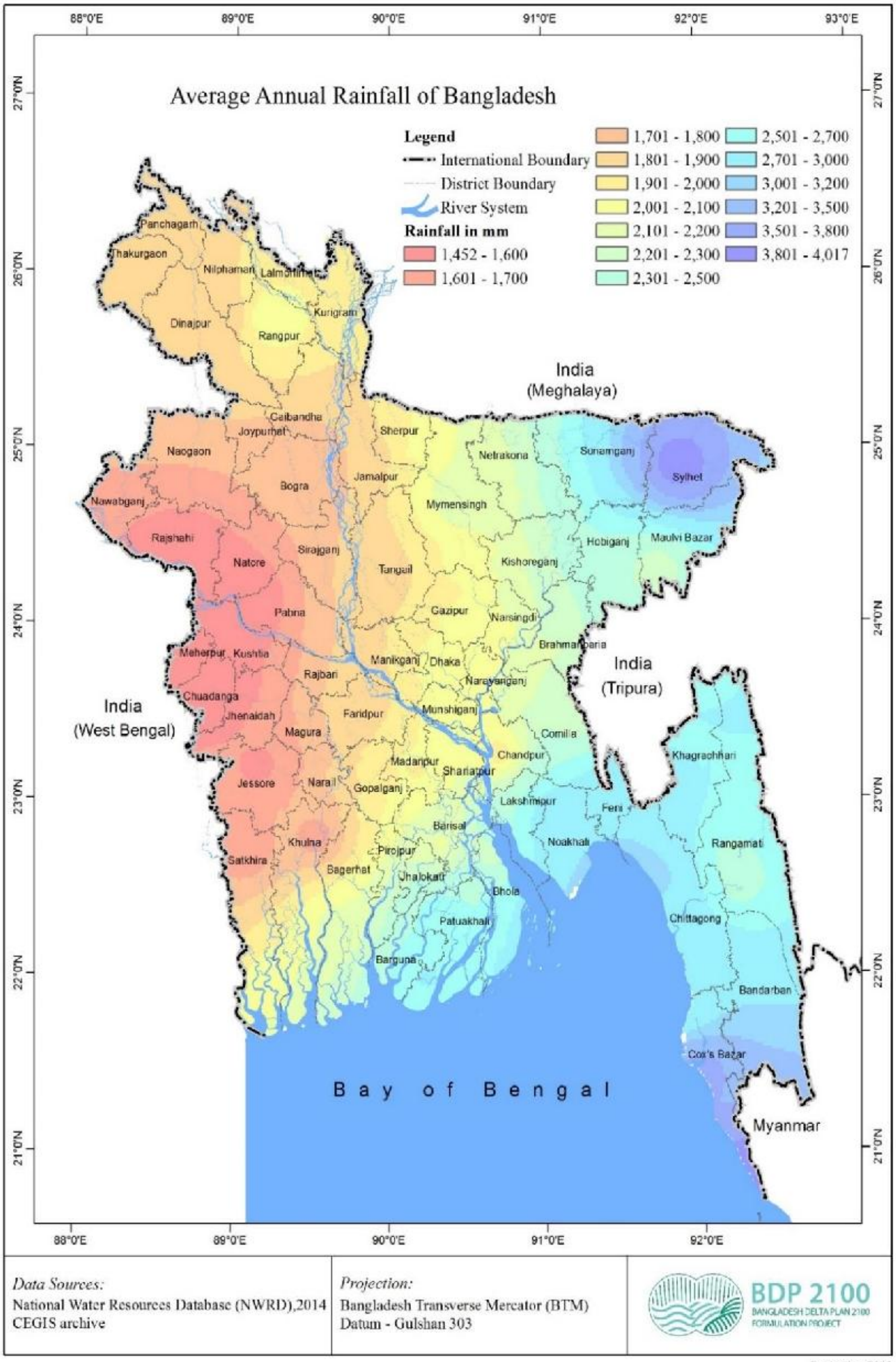

Figure 2.5: Average annual rainfall

Source: CEGIS, from the NWRD

The climate and physiography of the country (see also Annex for the Physiographic map of Bangladesh) lead to a pattern of monsoon floods in the wet season and water scarcity during the dry season. As can be seen from the table above, less than 5% of the mean annual (dependable) rainfall occurs during the five month dry season between November and March, making irrigation a necessity for crop production. Potential evapotranspiration is uniform around the country at approximately 1300 mm per year (NWMP, 2004). The monthly distribution of rainfall and potential evapo-transpiration for six hydrological regions is shown in **Figure 2.6**: Monthly rainfall and ET0 distribution (1985 -2009) in six regions

Source: CSIRO, 2014. A clear deficit is observed in the dry period from November to April, with the largest deficit occurring in the North-west and South-west regions.

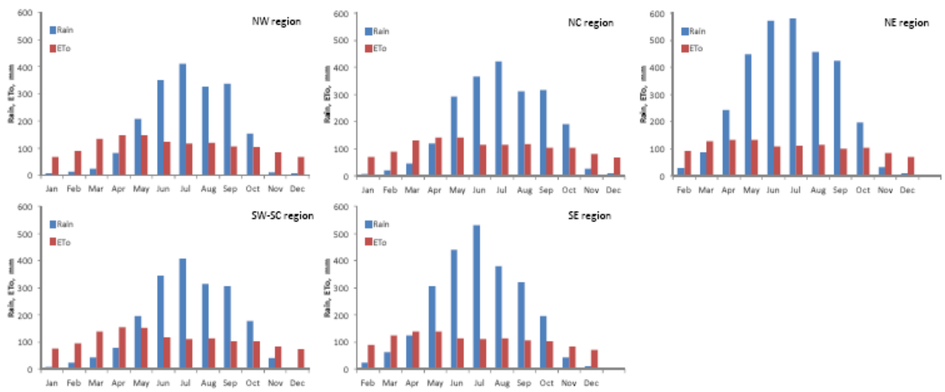

Figure 2.6: Monthly rainfall and ET_0 distribution (1985 -2009) in six regions

Source: CSIRO, 2014

Climate variability

Climate variability is a common feature of the country's climate, and one of the key challenges facing the (rural) population. Annual rainfall in Rajshahi and annual average maximum temperature variations in the Barind Tract are shown in **Figure 2.7** and **Figure 2.8** respectively.

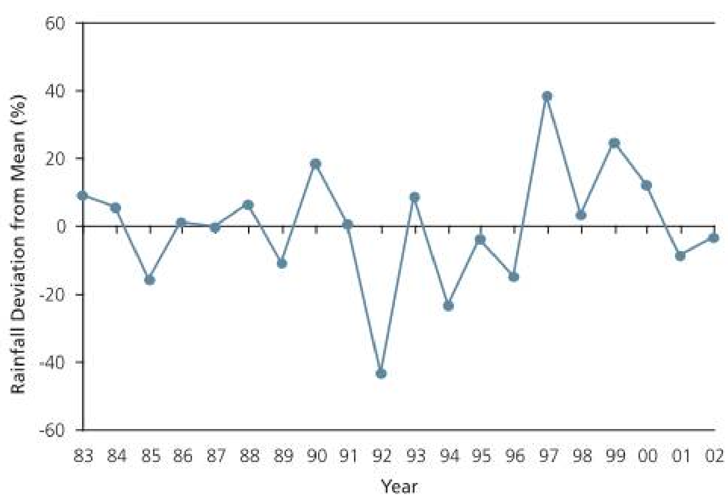

Figure 2.7: Annual rainfall in Rajshahi (1983 - 2002)

Source: Climate variability and change: adaptation to drought in Bangladesh, FAO, 2007

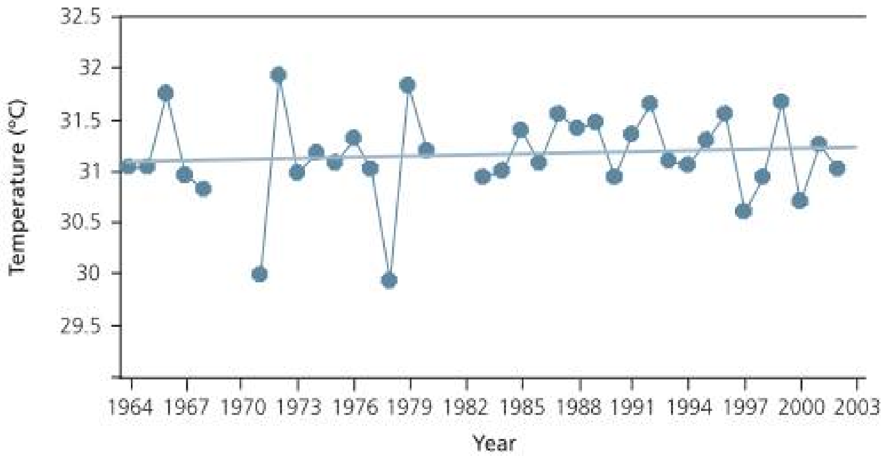

Figure 2.8: Annual average maximum temperature variations (1964-2003) in the Barind tract

Source: Climate variability and change: adaptation to drought in Bangladesh, FAO, 2007

According to CSIRO (2014), climate variability in Bangladesh is more pronounced than the range of climate change per se (**Figure 2.9**). Climate change model outcomes indicate a significant rise in temperatures, on both spring and summer periods, with a small and indicative rise, depending on the models used, of rainfall. A possible impact on spring flows due to earlier and more widespread glacier melting could also be observed, with possibly less recharge to groundwater as a result (CSIRO, 2014). Climate variability – variation from year to year in terms of total rainfall and its timing - are however much larger, as illustrated in Figure 9 below. The Baseline Study on Climate Change provides an in-depth analysis of future climate change.

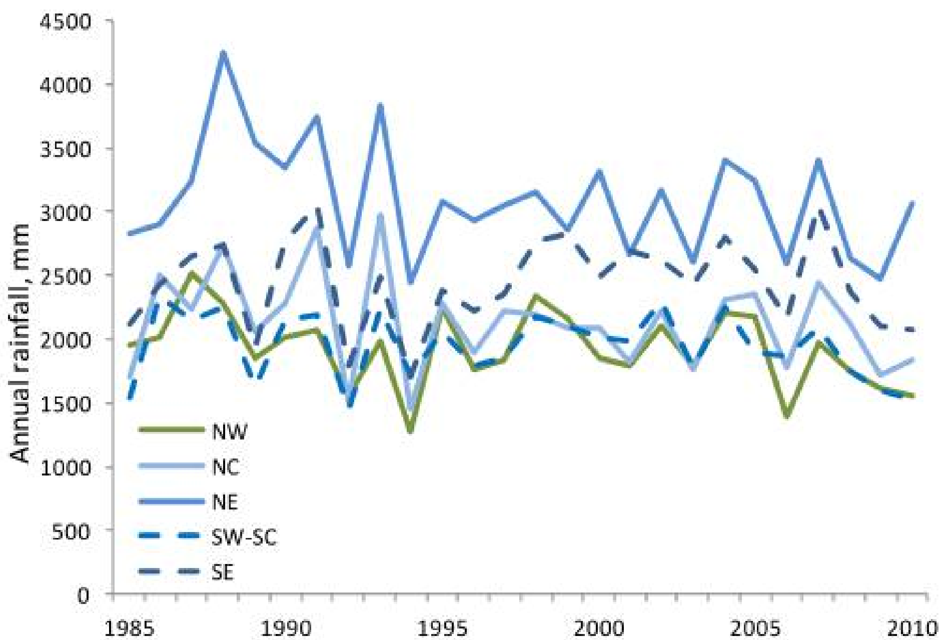

Figure 2.9: Annual rainfall variation for 6 hydrological regions of Bangladesh (1985 – 2010)

Source: CSIRO, 2014

2.4. Surface Water Resources

2.4.1. The river system

The surface water system of Bangladesh is made up out of a vast network of approximately 24,000 kilometres (A.A. Rahman, S. Huq and G.R. Conway, 1990), of major and minor rivers, of which the Ganges, Brahmaputra and Meghna are the most significant. 405 rivers crisscross the country, of which 57 are trans-boundary (BWDB, Land of Rivers, 2014). The rivers constitute the worlds' second largest riverine drainage basin and third largest freshwater outlet to the world's oceans, being exceeded only by the Amazon and the Congo River systems (Chowdhury and Ward, 2004). The Ganges-Brahmaputra-Meghna (GBM) basins cover five countries, including India (62.9%), China (19.1%), Nepal (8%), Bangladesh (7.4%) and Bhutan (2.6%). All three major river systems drain to the Bay of Bengal through Bangladesh. The river system of this delta has evolved through various changes in the last 250 years. The rivers abandoned their courses and subsequently occupied other new courses. Avulsion of major rivers has triggered major hydrological changes over the years (Baseline Report on River Systems Management, BDP, 2015, **Figure 2.10**). A detailed analysis of the countries' river system and major changes therein due to geological and climate changes, as well as a detailed description of the rivers in each Hydrological Regions (HR) is provided in the same baseline report (River Systems). A map of the river systems in each HR is provided in Annex 1 Factsheets of the Hydrological Regions.

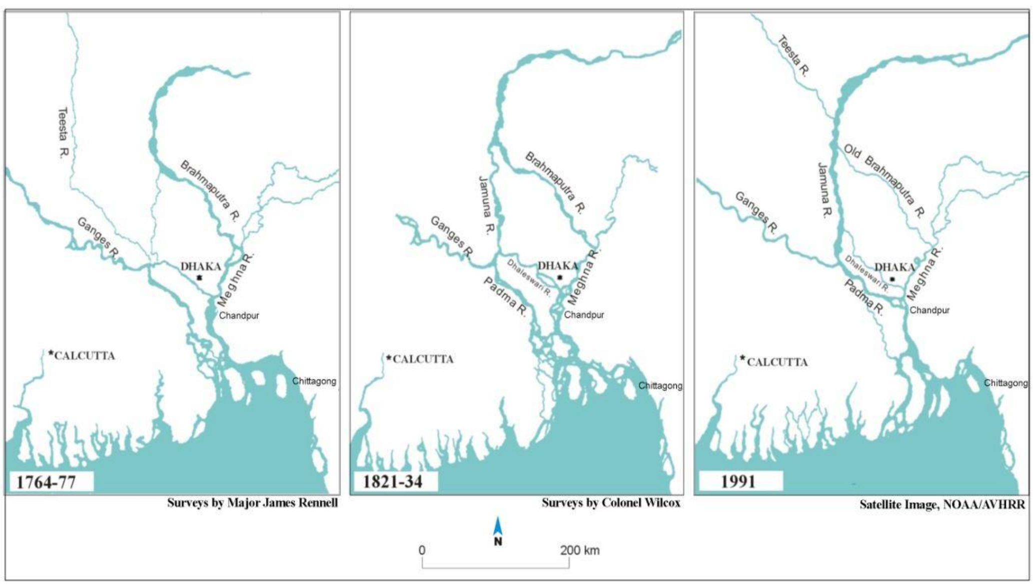

Figure 2.10: Main changes in the main river system of Bangladesh

Source: Baseline Report on River System Management, BDP 2015

The *Brahmaputra River* enters Bangladesh from the north, flows south for 270 km to join the Ganges River at Aricha, about 70 km west of Dhaka in central Bangladesh. The river changes its name to Jamuna at the point where Brahmaputra meets the Teesta River. The Brahmaputra-Jamuna is characterised by its braided nature, shifting sub-channels, and for the formation of chars within the channel. Within Bangladesh, the Brahmaputra-Jamuna receives four major right-bank tributaries - the Dudhkumar, Dharla, Teesta and Hurasagar. The first three are flashy, rising in steep catchments on the southern side of the Himalayan system between Darjeeling and Bhutan. The Old Brahmaputra and the Dhaleshwari are the important left bank distributaries of the Jamuna. Prior to the 1787 Assam flood, the Brahmaputra was the main channel; since then the river has shifted its course southward along the Jhenai and Konai rivers to form the broad, braided Jamuna channel (Ashworth et al, 2007). The Old Brahmaputra is now mainly active during the monsoon. Taking off at Bahadurabad, the river flows southeast and joins the Meghna at Bhairab Bazar. Flowing in a south-easterly direction, the Dhaleshwari bifurcates into two main branches: the Kaliganga and the Buriganga; the latter flows through the capital city, Dhaka.

The *Ganges* River enters Bangladesh about 18 km below Farakka Barrage (left side falls in Bangladesh). Main tributaries on the left side include the Mahananda, Punarbhaba, Atrai and Karatoya, which originate in India. The Ganges River flows east and south-easterly for 212 km from the Indian border to its confluence with the Brahmaputra, then flows as the Padma for about a further 100 km to its confluence with the Meghna River at Chandpur. Within Bangladesh, the Mahananda tributary meets the Ganges at Godagari in Rajshahi and the distributary Baral takes off at Charghat on the left-bank. The important distributaries taking off on the right-bank are the Mathabhanga, Gorai, Kumar, and Arial Khan.

The *Meghna* River flows southwest, draining eastern Bangladesh including the hills of Assam, Tripura and Meghalay of India to join the Padma at Chandpur. The Meghna then flows southward for 160 km and discharges to the Bay of Bengal. The Meghna is the longest (669 km) river in Bangladesh. The main source is the Barak river in India, the catchment area of which is located in the Naga-Manipur hills bordering Myanmar. The Barak-Meghna has a length of 950 km of which 340 km lie within Bangladesh.

Table 2.3: Total length and catchment of the great rivers

River	Ganges (incl. Padma)	Brahmaputra (incl. Jamuna)	Meghna
Length (km)	2510	2900	210
Length in Bangladesh (km)	220	240	264
Catchment (km^2)	1087300	552000	82000
Average rainfall (mm)	1200	1900	4900
Average annual discharge (m^3)	11000	20000	4600
Max. discharge (m^3)	78000	100000	20000
Sediment transport (m ton/year)	550	590	13

Source: Amarsinghe and Sharma, 2010 and BDP Baseline Report on Geo-morphology and River management

The *Teesta* is the fourth major trans-boundary river in Bangladesh. The origin is located in the Indian State of Sikkim where it originates from the Lake Lahmo at a height of 5330 metres (IUCN, 2014b). Before the Teesta River enters Bangladesh it flows through Sikkim and West Bengal. In Bangladesh, the river discharges into the Brahmaputra. The total length of the river is 309 kilometres and it drains an area of 1540 km^2.

In addition to the four major rivers mentioned above, some 53 additional trans-boundary rivers, such as the Dharla, Dudhkumar, Surma and Kushiyara, contribute to the trans-boundary river inflow of Bangladesh, three of which enter the country from Myanmar. Some 350 rivers originate within the country itself, thus forming an intricate pattern of major and minor rivers, draining the whole country into the Bay of Bengal. The total number of rivers in Bangladesh is 405 (Rivers of Bangladesh, BWDB, 2014).

Figure 2.11: Main Rivers of Bangladesh

Source: Prime Ministers' Office Library: **http://lib.pmo.gov.bd/maps/**

The *Chittagong region* is not part of the GBM basin and is formed by the 5 hilly districts of Chittagong Division. The main river of this region is Karnaphuli River, which drains the northern catchments of the region, and its tributaries Chengri, Myani and Kasalong. Karnaphuli River has been dammed at Kaptai to create a water reservoir for hydroelectric power generation. The three major rivers in the north originate in Tripura and flow south towards Bangladesh into the Kaptai reservoir. Before the creation of the Kaptai reservoir, the Chengri River and Myani River flowed into the Karnaphuli River. The Matamuhuri and Sangu Rivers originate in the mountains of Myanmar. All these rivers contribute to the Kaptai reservoir. Other important rivers of the region are the Feni, Muhuri, Sangu, Matamuhuri, Bakkhali, and Naaf rivers. In the region, the main sources of water are the surface water of rivers, lakes, canals and springs, and groundwater from shallow and deep aquifers. Rainwater is an alternative source of water in those areas where rainfall is comparatively high. All rivers enter into the Chittagong coastal plain and ultimately draining into the Bay of Bengal.

The GBM rivers have the largest total sediment load in the world, derived principally from the Himalayan and Indo-Burman ranges (Uddin and Lundberg 1998). The large sediment load, coupled with a dynamic hydraulic regime, causes the rivers to be morphologically very active and extremely dynamic. The Brahmaputra (and Jamuna), Ganges and Padma are braiding rivers and subject to active erosion and sedimentation processes. On average, some 6000 ha of river bank erosion occurs in the country on an annual basis, leading to the displacement of about 50000 people. Total erosion and accretion for the period 1973 – 2013 can be found in the table below. A detailed analysis of river erosion, accretion and morphology can be found in the Baseline Report on River Systems Management (BDP, 2015). Erosion and accretion in the coastal zone is discussed in the Baseline Report on Coast and Polder Issues, BDP, 2015).

Table 2.4: River erosion and accretion, 1973 - 2013 (CEGIS Erosion Prediction, 2014)

River	**Area eroded (ha)**	**Area accreted ha)**
Brahmaputra/Jamuna	90367	16444
Ganges	29842	25009
Padma	33229	11545
Lower Meghna	25820	22265
TOTAL	179258	75263
Net river erosion	103995	

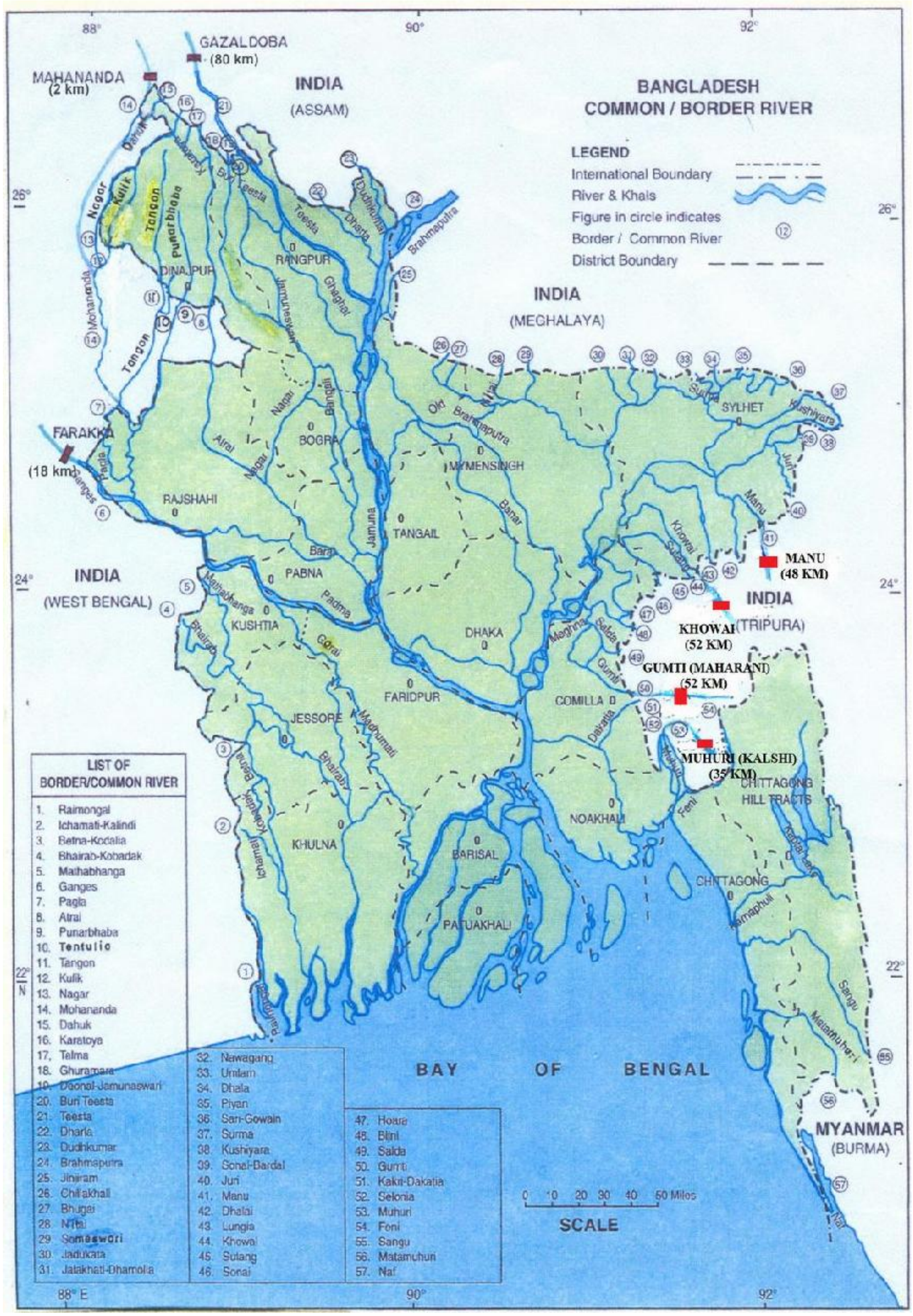

Figure 2.12: Trans-boundary Rivers of Bangladesh

Source: JRC, http://www.jrcb.gov.bd/

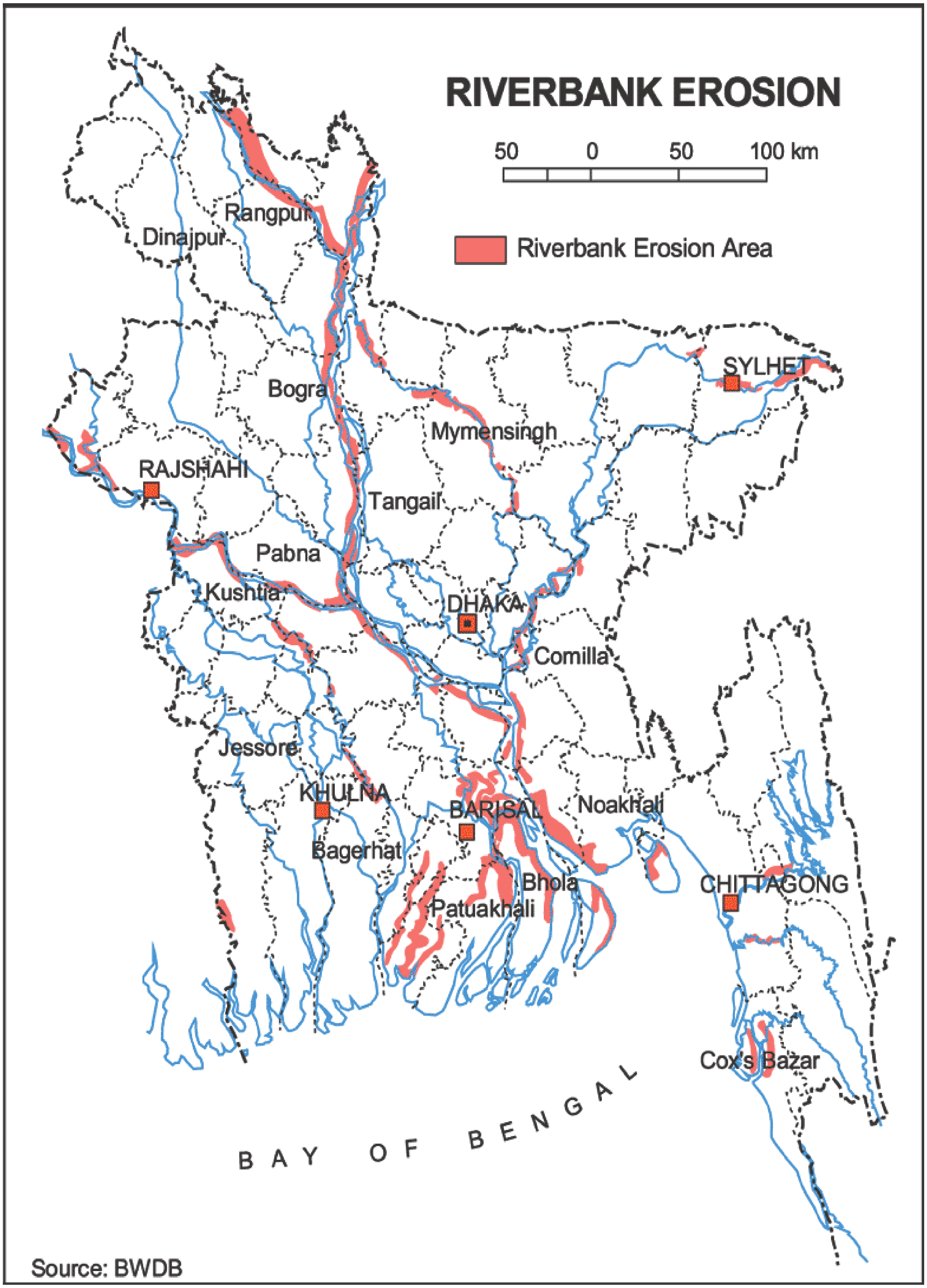

Figure 2.13: River Bank Erosion in Bangladesh

Source: Prime Ministers' Office Library, **http://lib.pmo.gov.bd/maps/**

2.4.2. Wetlands, water bodies and lakes

A network of *beels*, *haors, baors*, lakes, khals, and *ponds* exist in the country, comprising a rich source of water bodies. Some of them remain under water for the whole year whilst others are submerged in the wet season only.

Haors are bowl or saucer shaped depressions and mostly seen in the north-eastern part of the country, in the Sylhet Basin. The Haor area constitutes a mosaic of wetland habitats, including rivers, streams and irrigation canals, large areas of seasonally flooded cultivated plains, and hundreds of haors and beels. This zone contains about 400 haors and beels, varying in size from a few hectares to several thousand hectares. Haors are a vital resource for fisheries, irrigation water, ecosystem functioning and navigation. The Sylhet Basin is tectonically active and subject to gradual subsidence. Subsidence is further exacerbated by the westward avulsion of the Brahmaputra which, in turn, has decreased the sediment supply to the basin. The total number and area of the Haors in the NE Region is indicated in the table below:

Table 2.5: District wise area and number of Haors (Haor Master Plan)

District	Haor area (ha)	No of Haors
Sunamganj	268531	95
Habiganj	109514	14
Netrakona	79345	52
Kishoreganj	133943	97
Sylhet	189909	105
Maulvibazar	47602	3
Brahmanbaria	29616	7
TOTAL	858460	373

Beels are usually depressions or topographic lows, produced by erosion or other geographical processes. These are generally smaller and seen all over Bangladesh. Occasionally, beels are remains of a river that has changed its course. Many beels dry up in winter and expand during the monsoon season into large and shallow water bodies. Beels are generally smaller than haors, but there also are large beels like Chalan Beel[1] (in Rajshahi Division), through which the Atrai River passes. It has shrunk over the years and now occupies an area of 26 km^2, comprising some 93 smaller water bodies, in the dry season[1] (BDP Hot Spot Delta Atelier, Rajshahi, June 2015, and (M Hossain, 2009). Occasionally, small permanent water bodies within the haors remain after the haors dry up. These are also called beels, which occupy the lowest part of the depressions.

A third category is the *Baor* or oxbow lake, mostly found in the moribund delta as in greater Comilla, Faridpur, Dhaka and Pabna districts.

Kaptai Lake is the largest (permanent) lake in the country, covering an area of around 777 km2, created after the construction of Kaptai dam for hydro power generation. The average annual flow in the reservoir is approximately 15646 million m^3. The flood absorption capacity is 1024 million m^3. Another prominent lake is Bogakine Lake, which is a natural lake situated in the Bandarban district in the Chittagong Hill Tracts. Other lakes include Rinkhyongkine and Foys, all situated in the Eastern Hills (EH) HR, Chittagong Division.

[1] According to Hossain, 2009, most of the rivers and beels in Chalan Beel are at risk of partial or total degradation, as a result of agricultural encroachment, siltation and other anthropogenic activities

The natural drainage channels are referred to as *khals*. They are a common feature in all areas and serve a number of purposes, including navigation, fisheries (both migration and capture), water retention and drainage. In many FCDI projects, khals are enlarged or otherwise modified to improve internal drainage of the areas or enhance storage of fresh water for irrigation.

An estimated 1.3 million *ponds* exist in the country, covering some 151000 ha or 11% of the permanent inland water area (FAO, 2011). In general, the size of the ponds varies between 0.02 and 20 ha with an average of 0.30 ha. In Bangladesh, the highest number of ponds exists in the Barisal district (12.11%), followed by Comilla (9.36%), Sylhet (9.10%), Chittagong (8.02%) and Noakhali (7.75%) (BBS, 2002 and FAO, 2011). Before the introduction of tubewells in the 1960s' and 1970s', ponds were an important source of drinking water in the rural areas (M Sekandar Khan, in Conway et al, 2000). Up to 80% of women make use of ponds for their needs, including water for cooking and bathing (NWMP, 2004).

An overview of the main (permanent) wetlands in the country id provided here below:

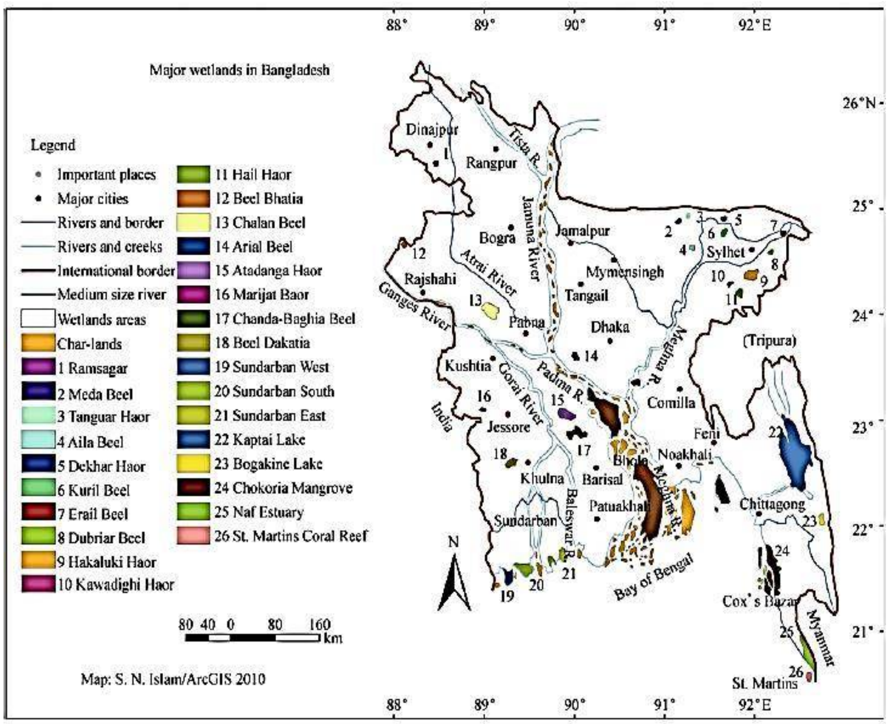

Figure 2.14: Major wetlands in Bangladesh

Source: http://amaderpani.org/designated-wetlands-in-bangladesh/

The total area covered by open and closed water bodies is some 43980 km^2, as presented in the table below (**Table 2.6**). The wetlands and water bodies are vital for the ecological functioning of the delta, and provide a key source of livelihood for many rural poor in the country. Over 70% of the rural households in the floodplain catch fish either for income or for food (Thompson et al, 1999) and about 60% of animal protein consumption comes from fish (BBS, 1999). The fisheries sector contributes 3.74% of the gross domestic product (GDP), 20.87% of agricultural resources and 4.04% of foreign exchange earning of Bangladesh (DoF, 2009). Total fish production of the country during the 2007-2008 was about 2.57 million metric tons of which 2.065 million metric tons were produced from freshwater including culture fisheries and 0.04 million metric tons from marine water including shrimp (DoF, 2009).

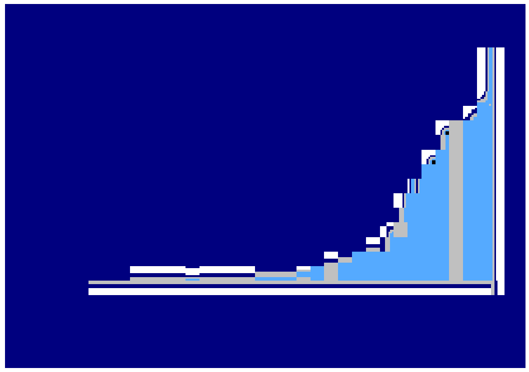

Figure 2.15: Increase in fisheries production in Bangladesh (FAO, 2011)

Fish and fishery products are the country's third largest export commodity contributing 5.1% of its exchange earnings (FAO, 2011), 4.91% of GDP and provides 63% of the national animal protein consumption (DoF, 2003.)

Table 2.6: Total area of water bodies in Bangladesh (Bangladesh National Consultation, 2014)

Open Water Bodies			**Closed Water**		
River and Estuaries		10320 km^2	Ponds		2150km^2
Beels and Haors		1140km^2	Baors		50km^2
Kaptai Lake		680km^2	Coastal Lowlands		1410km^2
Flooded Land (average)		28330km^2			
Total		40470km^2	Total		3510km^2

2.4.3. Decrease of Wetlands in Bangladesh

Wetlands provide key environmental services such as habitats for fish spawning, assimilation of wastes, flood attenuation, navigation and recharge to groundwater. In additional they host a wide variety of flora and fauna, many of which are protected by national under international legislation. Wetlands, both in terms of their extent (area and volume) and biodiversity are however in serious decline in the country. Out of Bangladesh's 260 freshwater fish species (Rahman, 2005), more than 40% are now threatened with extinction (IUCN Bangladesh, 2000). Based on Landsat image interpretation during three dry seasons of 1989, 2000 and 2010, it was found that the total wetland area in the North-west region (the region with the largest number of beels in the country) declined from 1208.72 to 903.54 km^2 in 2000 and 867.18 km^2 in2010. This indicates a decrease of 25.25% wetland areas from 1989 to 2000 and 4.02% decrease in wetland areas from 2000 to 2010 (Estimation of the changes of wetlands in the northwest region of Bangladesh using Landsat images, Shopan et al, 2013).

Mahmud et al. (2011, in Shopan et al, 2013) evaluated wetland changes in Dhaka Metropolitan Area between 1978 and 2009. The analysis revealed that area of wetland and Rivers & Khals in Dhaka city decreased significantly over the last 30 years by 76.67% and 18.72% respectively. Land filling and encroachment were recognized to be the main reasons for shrinking of the wetlands in the city. Islam et al. (2010, in Shopan et al, 2013), in a separate study, observed that in the Dhaka city water bodies and lowlands decreased by 32.57% and 52.58%, respectively during 1960 and 2008.

2.4.4. Surface water quality

Surface water quality issues in Bangladesh can be divided into two broad categories: *salinity* and *pollution*.

Salinity in the coastal areas is a normal hazard, but in the South-west it has been accentuated by the reduction in dry-season flows entering the Gorai distributary. Surface water salinity in coastal area depends on the volume of freshwater discharges from the upstream river systems, the salinity of the Bay of Bengal and the circulation pattern of the coastal waters induced by the ocean currents and the tidal currents in the coastal waters. A reduction in freshwater inflows from the upstream of the Ganges River, siltation of the tributaries of the Ganges, and siltation of other rivers following the construction of the coastal polder system has resulted in a significant increase in river salinity during the dry season (River Salinity and Climate Change, World Bank Policy Research Working Paper 6817, 2014). Salinity now reaches as far as Khulna (**Figure 2.16**), and affects the supply of clean water for industrial use, particularly for cooling water use. Salinity is also a problem for Chittagong when there are no releases from Kaptai Lake (NWMP, 2004).

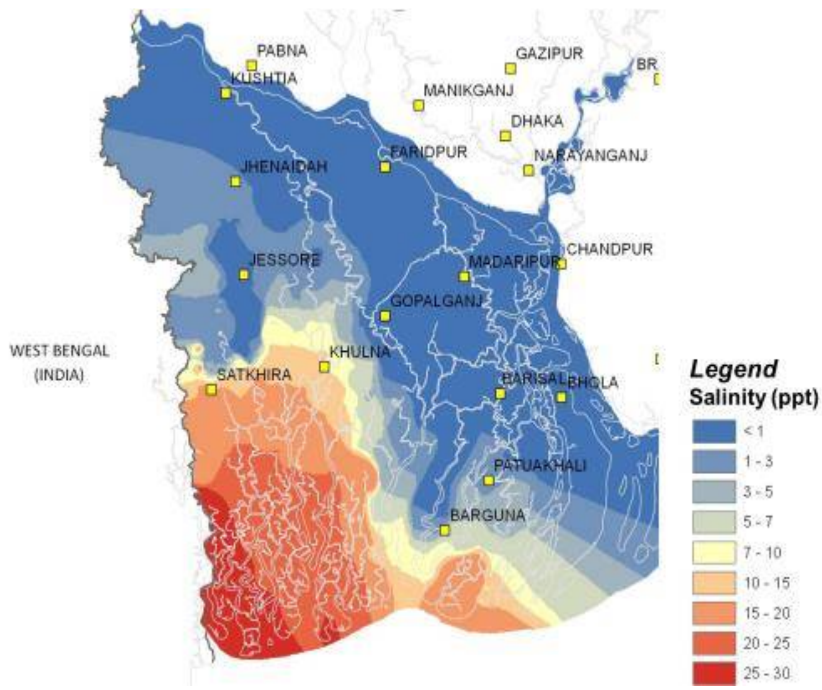

Figure 2.16: Average maximum surface water salinity during 2011–12 in South-west region

Source: IWM, 2014

Pollution of surface water is of a very different nature and caused by three major categories of contamination: domestic/municipal, agricultural and industrial. Sources of pollution include (adapted from Aftab Uddin Ahmed and Mohammad Reazuddin, in Conway et al, 2000; NWMP, 2004 and Abdul Matin, undated):

i) Industrial effluent discharge, treated and untreated
ii) Power stations causing thermal pollution through discharge of cooling water
iii) Municipal sewage and effluent discharge, treated and untreated
iv) Pollutants emanating from rural communities, including faecal contamination of ponds
v) Residual pesticides and nutrients
vi) Oil and oil products
vii) Hospital wastes

An important indicator of pollution is the Dissolved Oxygen (DO), especially for fish life. Model computations shown in **Figure 2.17** below illustrate the impact that pollution on this key indicator – DO. A recent test by DWASA showed an extremely low levels of DO (**Figure 2.17a**).

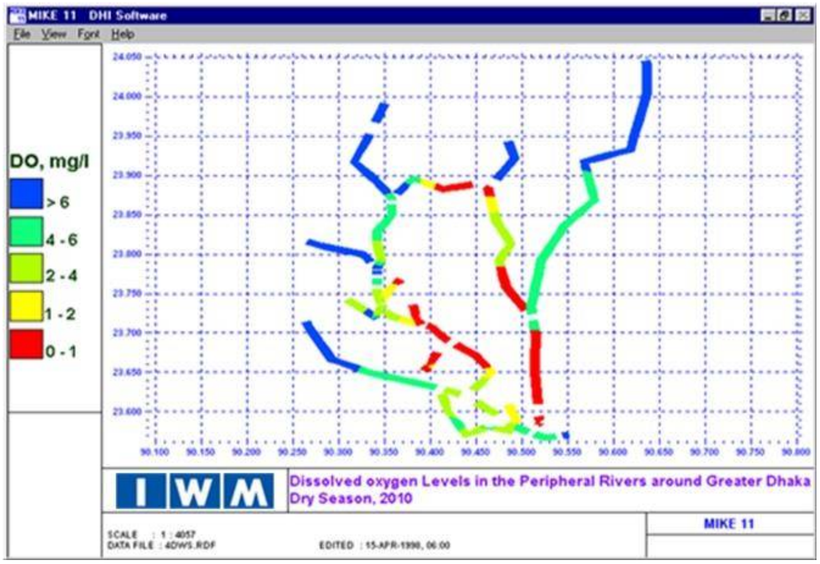

Figure 2.17: Dissolved oxygen in rivers around Dhaka, 2010 dry season

Source: Water Quality modelling by IWM 2010

About 11% of the rivers in Bangladesh are polluted by *industry wastes* and 32 rivers are considered as having severe pollution from industry (Matin, undated). Most of the industries are located on the banks of the rivers, as can be observed in the map (**Figure 2.19**). Key polluting industries include textiles, tanneries, pulp and paper mills, distilleries, fertilizer and chemical industries (adapted from Conway et al, 2000). Hazardous chemicals of both organic and inorganic compositions are discharged into the water bodies from all of these industries, often without adequate treatment. The highest number of industries in the country are located in and around big cities such as Dhaka, Chittagong and Khulna.

Some 65% of all chemicals, plastics and petroleum industries, totalling some 7000 industries, are concentrated in and around the Dhaka Watershed, in three districts, Dhaka, Narayanganj and Gazipur (Minnatullah, 2010, Environmental Consultation, World Bank, Bangladesh). The most polluted rivers are Buriganga and Shitalakhya. According to a 2007 World Bank study (IWM, 2007), some 1.3 million m^3 of waste is discharged per day into the rivers of Dhaka watershed (Buriganga, Shitalakshya, Turag, Balu, Bangshi, Dhaleswari & Tongi Khal). Industrial discharge is 60% of the total load while domestic discharge is 40%. In addition, the sewerage system is overloaded and functions at only 30% of demand. Prolonged pollution, especially in the Hazaribagh industrial area, also leads to contamination of sediments, the shallow and, in due course, the deeper aquifers by the main pollutants used in the tannery. This has been explored in Zahid (2006) in his research on (potential) groundwater pollution for the Hazaribagh industrial zone.

Agricultural contamination, although still relatively low, is affecting the water quality of ponds and beels country-wide. About 1.6 million tons of chemical fertilizers and 4000 – 5000 tons of pesticides are used in agriculture annually. Though illegal, the notorious 'dirty dozen' group of illegally imported 9 out of 12 Persistent Organic Pollutants (POPs) are also being used for agricultural & household purposes [2] (Matin, undated).

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[2] Eldrin, Dieldrin, Chlorden, DDT, Endrin, Heptochlor, Mirax & Toxafen

Domestic contamination in rural areas, amongst others with faecal coliforms, although not well quantified, is a serious form of contamination, due to the untreated disposal of human waste into ponds, beels and rivers. For details, please refer to Baseline Study on Environmental Pollution, plus others (list of Reference).

Unpublished data collected for DWASA (to be verified) show extremely low levels (<1 mg/l) of Dissolved Oxygen (DO) in the Buriganga, Balu, Sitalakhya and Dhaleshawri Rivers in May 2015. A large number of the rivers around Dhaka are almost anoxic showing black water with a pungent smell and allowing no aquatic life. During the Monsoon (July August data) the water quality is somewhat better. However, DO levels still do not meet water quality standards with DO level s varying from 2 to 4 mg/l. The same data set also shows that the nutrient concentration in the rivers is very high. Ammonia levels up to 15 mg N/l can be found. Phosphorus concentrations vary between 1 and 6 mg P/l. During long low flow periods these high nutrients levels lead to severe problems of eutrophication. Recent monitoring data show the impact that pollution is having on this key indicator in the DMA. The red areas, in which DO levels fall below 1 mg/l, during the dry months from January to March, occur primarily in the Buriganga, Tongi Khal, Balu and Sitalakhya Rivers.

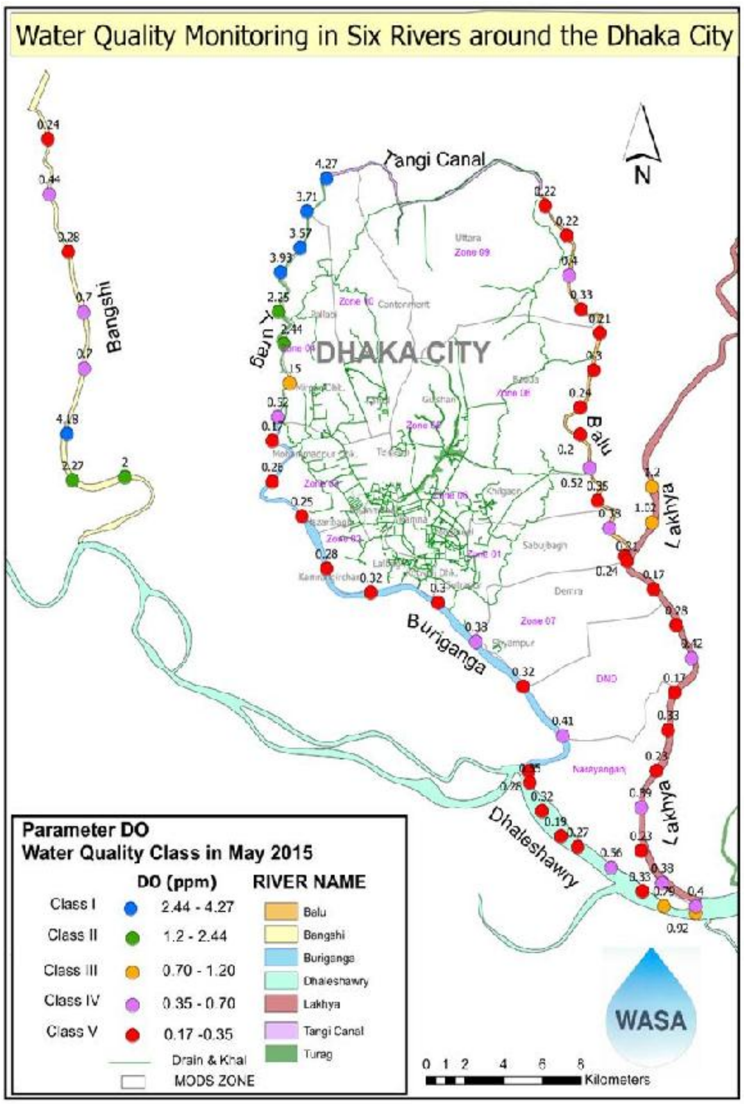

Figure 2.18: Dissolved oxygen in rivers around Dhaka, 2015 dry season, Monitoring data DoE

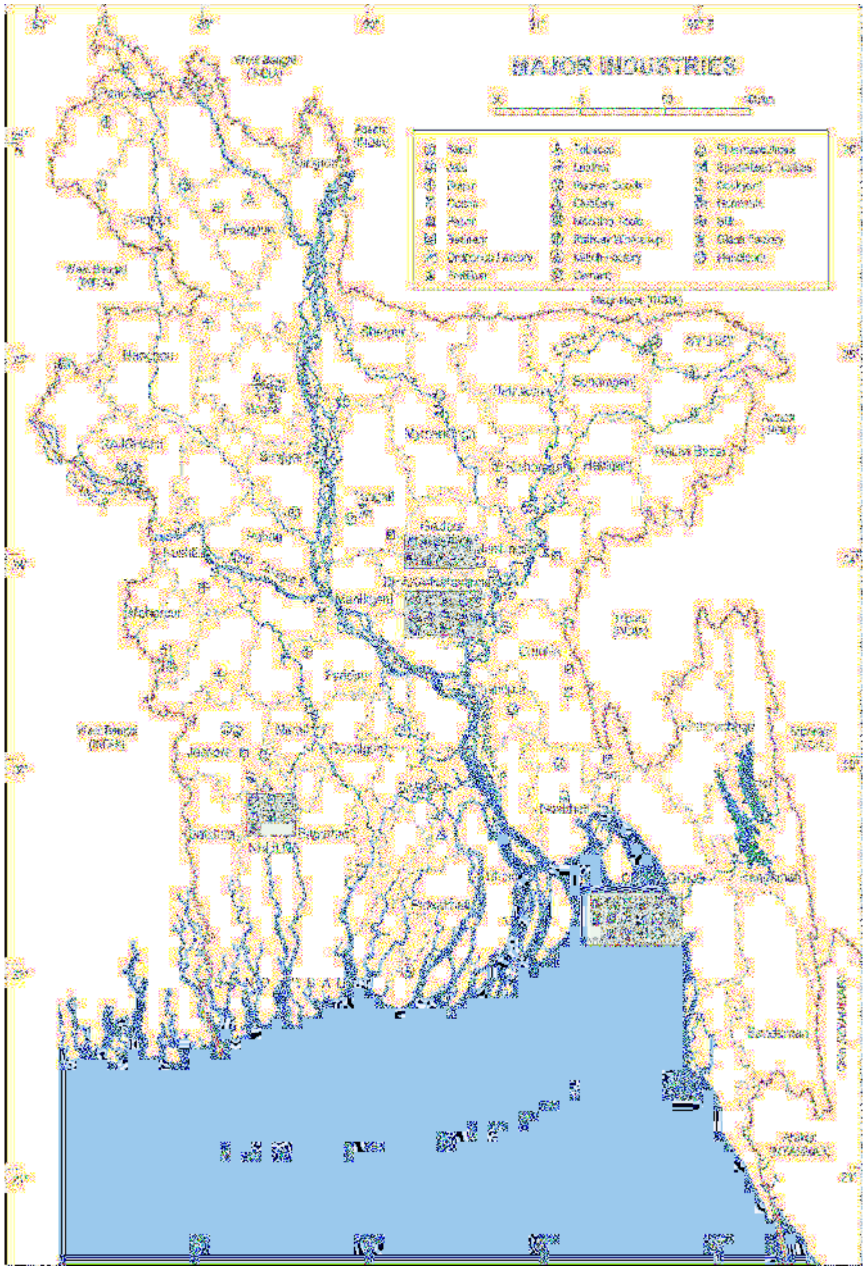

Figure 2.19: Industries in Bangladesh

Source: Prime Minsters' Office Library: **http://lib.pmo.gov.bd/maps/**

There are at least three types of direct negative impacts of water pollution: i) increasing health problems of the rural and urban population [3], also leading to increased deaths [4]; ii) loss of agricultural and industrial productivity;

[3] Typically: Typhoid, Skin Disease, Jaundice, Kidney Disease and Diarrhoea

[4] According to the WHO (WHO, in UN Water Country Brief, 2013) water, sanitation and hygiene-related deaths comprise 8,5% of total deaths in the country

and iii) environmental degradation, leading to a series of further impacts [5]. All of these lead to an increasing economic cost, both as a result of productivity loss and as a result of the need for – more expensive - alternatives to the environmental services offered by the water system. A comprehensive national survey on these impacts has not yet been undertaken, but results from regional studies, especially around the Dhaka area, do show a clear, and worrying, pattern:

- Health care cost of pollution represents 21.5% of annual income in Hazaribag area (IWM, 2007);
- The loss of amenities associated with contaminated surface water amounts to about 0.5% of the region's GDP (World Bank, 2010);
- In polluted areas of Dhaka Statistical Metropolitan Area (DSMA), 45% of households report persistent losses in the production of rice and more than 20% are experiencing production losses in vegetable crops. Less than 15% of households in highly polluted areas allow livestock to drink river water, compared with more than half in the past. It is estimated that agricultural and fisheries production in the DSMA may be reduced by about one third as a result of poor water quality (Bangladesh Environmental Management Project, BEMP, 2005). Estimated annual costs amount to some US$400 million linked to poor surface water quality, including lost agricultural and fisheries production (17%), costs to industry (22%), lost amenity (21%), and health costs (40%).

2.4.5. Surface Water Availability

Data on the total available water resources in Bangladesh vary considerably and depend on definitions used. According to FAO (Aquastat, 2011), the long-term average Total Renewable Water Resources (TWRR) are 1211 bcm/year, amounting to a per capita availability of 8051 m^3 per year. TRWR is the sum of the Internally Renewable Water Resources (IRWR): the sum of the water resources available through endogenous precipitation, and the Externally Renewable Water Resources (ERWR): the sum of the inflows from surface and groundwater from outside the country. Internal renewable water resources (IRWR) are estimated at 105 bcm, of which 84 bcm originate from surface- and 21 bcm from groundwater. Externally renewable water resources total 1106 bcm, of which 0.03 bcm comes from groundwater. The country thus avails of a total of 1211 bcm of Actual Renewable Water Resources, according to FAO (2013). Of these, 1189.5 bcm are surface water and 21.1 bcm are groundwater resources.

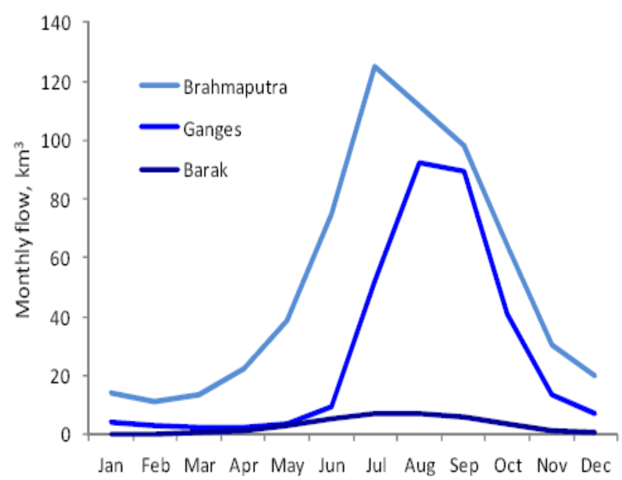

Figure 2.20: Monthly border inflows of the three main trans-boundary rivers, averaged 1980 - 2009 *(IWM, 2014)*

Mac Kirby et al (2014) estimate annual cross-border river flows and entering groundwater and the river systems at 1260 bcm, of which the three main rivers contribute some 981 bcm (Mac Kirby et al, 2014). Of the latter amount, some 54% is contributed by the Brahmaputra, 31% by the Ganges and nearly 14% by the tributaries of the Meghna. 1% (11 bcm) is contributed by other minor rivers of the Eastern Hills. During the wet season, the rivers

[5] The impact of pollution on the provision of (environmental) services and goods from watersheds is not yet well understood or quantified

receive an additional flow of about 113 bcm from the combined regional (in-country) runoff. Dry season flows are an estimated 186 bcm or 15% of the total (Mac Kirby et al, 2014).

The volume of rainfall (excluding the Eastern Hills region) is estimated at 266 bcm by IWM (2013, in CSIRO, 2014), based on BWDB rainfall data for the period 1980 – 2009, and 284 bcm by Mac Kirby et al, based on BMD data. 11% of rainfall falls in the dry season from November to April.

In the NWMP (2004), a distinction is made between *static* and *fugitive* water resources, with static resources defined as 'those trapped on the surface of the land or as soil moisture' (the latter could also be considered as groundwater resources), and fugitive resources as 'the flows in the rivers'. The fugitive resources include net flows between the HR and the main river system.

Table 2.7: Estimated Volume of Useable Static Resources (Mm^3)

Hydrological Region		NE	NC	NW	SW	SC	SE	EH	Total
Component	Unit								
Residual Soil Moisture	Mm^3	1473	743	1065	893	450	543	960	6127
Stored	Mm^3	793	912	2384	739	209	591	28	5656
Total	Mm^3	2266	1655	3449	1632	659	1134	988	11783
HR area	km^2	31625	15950	20061	24344	12474	10144	19279	133877
Total	mm	72	104	172	67	53	112	51	88
Proportion (regional / national)	%	19%	14%	29%	14%	6%	10%	8%	100%

(Mm^3 = Million m^3)

Source: NWMP, Appendix C7, Table 7.7.2

Fugitive resources were computed as dependable flows, with 50% and 80% (statistical) dependability. Only the period from May to November was computed, considered the dry (relevant) season regarding water availability, in view of the current (very) low level of storage.

Table 2.8: Fugitive water resources per HR, 50% dependable

Hydrological Region	Unit	NE	NC	NW	SW	SC	SE	EH	Total (Nov-May)
Nov	m^3/s	1487	488	1190	1385	7068	488	522	12628
Dec	m^3/s	646	108	612	541	4199	139	129	6374
Jan	m^3/s	353	49	457	227	2603	95	92	3876
Feb	m^3/s	355	52	400	169	2088	122	146	3332
Mar	m^3/s	553	72	376	177	2477	181	507	4343
Apr	m^3/s	1736	177	428	225	4132	335	401	7434
May	m^3/s	4163	678	937	305	7162	603	1229	15077

Source: NWMP, Appendix C7, Table 7.8.2

Table 2.9: Fugitive water resources per HR, 80% dependable

Hydrological Region	Unit	NE	NC	NW	SW	SC	SE	EH	Total (Nov – May)
Nov	m^3/s	889	284	827	786	5928	340	341	9395
Dec	m^3/s	492	72	428	254	3817	90	94	5247
Jan	m^3/s	273	38	318	77	2354	84	71	3215

Hydrological Region	Unit	NE	NC	NW	SW	SC	SE	EH	Total (Nov – May)
Feb	m^3/s	293	48	287	72	1845	106	114	2765
Mar	m^3/s	393	63	276	93	2257	152	336	3570
Apr	m^3/s	1024	117	306	134	3534	317	259	5691
May	m^3/s	2286	434	595	186	5801	328	687	10317

Source: NWMP, Appendix C7, Table 7.8.2

Table 2.10: Fugitive water resources per HR, 50% dependable

Hydrological Region	Unit	NE	NC	NW	SW	SC	SE	EH	Total (Nov – May)
Nov	Mm^3	3855	1266	3086	1876	18321	1265	1354	31023
Dec	Mm^3	1729	290	1640	552	11246	371	344	16172
Jan	Mm^3	944	131	1225	142	6971	256	247	9916
Feb	Mm^3	866	126	977	149	5096	299	357	7870
Mar	Mm^3	1480	192	1007	283	6635	484	1359	11440
Apr	Mm^3	4500	459	1108	456	10709	1359	1039	19630
May	Mm^3	11150	1817	2510	513	19184	11441	3293	49908

Source: NWMP, Appendix C7, Table 7.8.2

Table 2.11: Fugitive water resources per HR, 80% dependable

Hydrological Region	Unit	NE	NC	NW	SW	SC	SE	EH	Total (Nov – May)
Nov	Mm^3	2305	736	2144	931	15365	882	885	23248
Dec	Mm^3	1318	194	1146	355	10224	241	251	13729
Jan	Mm^3	732	101	852	121	6305	224	190	8525
Feb	Mm^3	715	117	700	127	4502	260	279	6700
Mar	Mm^3	1054	170	738	233	6045	406	900	9546
Apr	Mm^3	2655	304	792	333	9159	823	671	14737
May	Mm^3	6122	1164	1594	384	15538	878	1840	27520

Source: NWMP, Appendix C7, Table 7.8.2

2.5. Groundwater resources

2.5.1. Importance and background

Groundwater is an important source of drinking and irrigation water in Bangladesh. Some 80% of irrigation originates from groundwater, particularly for the cultivation of Boro rice (source: FAO Aquastat, 2011). An estimated 21 bcm (MPO, 1997) of groundwater resources is produced within the country, with an unknown but estimated important quantity of groundwater flowing into the country through horizontal flow paths from the Himalayas. The contribution of the horizontal groundwater flow to the recharge of the deep aquifers is of crucial importance to prevent its depletion; however, this process is not well quantified. Estimates of groundwater recharge vary widely. Rajmohan and Prathaper (quoted in CSIRO, 2014), based on a review of several information sources suggest that the annual groundwater availability is about 65 bcm. The regional water balance study (Mac Kriby et al, 2014) suggests that the gross annual average recharge to shallow, unconfined groundwater in Bangladesh (excluding the eastern hills) is about 47 bcm. However, this includes percolation from irrigated rice crops of about 15 bcm which leads to a net recharge of about 32 bcm. The groundwater study by Hodgson et al.

(2014) suggests that the recharge is about 28 bcm. These widely varying figures serve to underline a key conclusion of Kirby et al. (2014) that components of the water balance for groundwater are not known and should be studied in more detail.

The geological history of Bangladesh is marked by a set of sea regressions and transgressions and the flowing of multiple rivers. Most of Bangladesh had low elevation throughout its geological history that made it very much sensitive to the sea-level changes which influenced geological processes of weathering, erosion and deposition of sediments. These conditions formed a deltaic system characterized by multi-layered sandy and gravel aquifers and scattered lentils of clay varying in length and thickness. This hydrogeological complexity, the proximity of the Himalayas and the sea, the seasonality of the climate, the natural geochemistry of the sediments, and the presence of big rivers and hundreds of smaller water courses, frame the groundwater system of the country. The geological and hydrological processes mentioned above were in operation throughout the Plio-Pleistocene and Holocene periods, making the GBM delta the largest delta and one of the largest deep sea fans in the world.

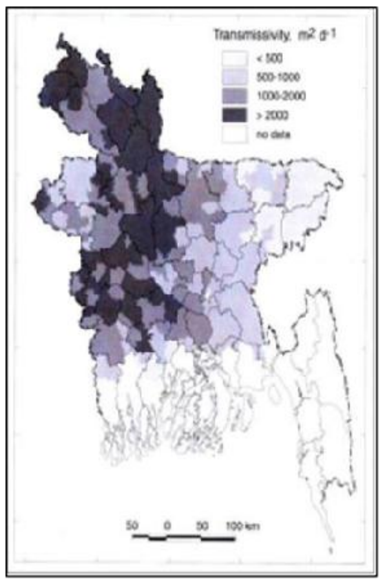

Figure 2.21: Variation in Transmissivity in Bangladesh (DPHE, 2000)

The Bengal Basin has more than 20 km of Tertiary-Holocene sedimentary fill below ground level, which consists predominantly of the organic sediments derived from both the eastern Himalayas to the north and the Indo-Burman Ranges to the east (Alam et al. 2003). This generalized sequence is not common in all parts of the country and in some places many formations are missing due to depositional, non-depositional, and post depositional erosion. The sediment thickness is shallowest in northern Bangladesh (100 m).

Traditionally, the aquifers of the delta plain and the flood plains of the GBM Delta Complex have been divided on the basis of depth. But, as the sedimentation rate and subsidence in the whole of the Bengal Basin was not uniform throughout the Quaternary, sediments of very different nature or of different geological age can be found at similar depths. An attempt has therefore been made to divide the aquifer systems in the GBM Delta Complex from a geological point of view with proposed divisions of the Late Pleistocene-Holocene sediments. According to Zahid (2015), this is more logical than the conventional divisions based only on depth. The major divisions in this classification are: 1) Plio-Pleistocene Aquifers; and 2) Late Pleistocene-Holocene Aquifers: a) Late Pleistocene-Early Holocene Aquifers; b) Middle Holocene Aquifers and c) Upper Holocene Aquifers (Zahid, 2015).

A detailed description of these different formations can be found in A. Zahid, Groundwater Management Aspects in Bangladesh, topical study prepared for the BDP, 2015.

On a national scale, the overall groundwater flow is from the North-west to the South-South-east. Transmissivity is highly variable both horizontally and vertically (from 249 m^2/day to 4384 m^2/day, depending on the geological formation, IWM, 2014).

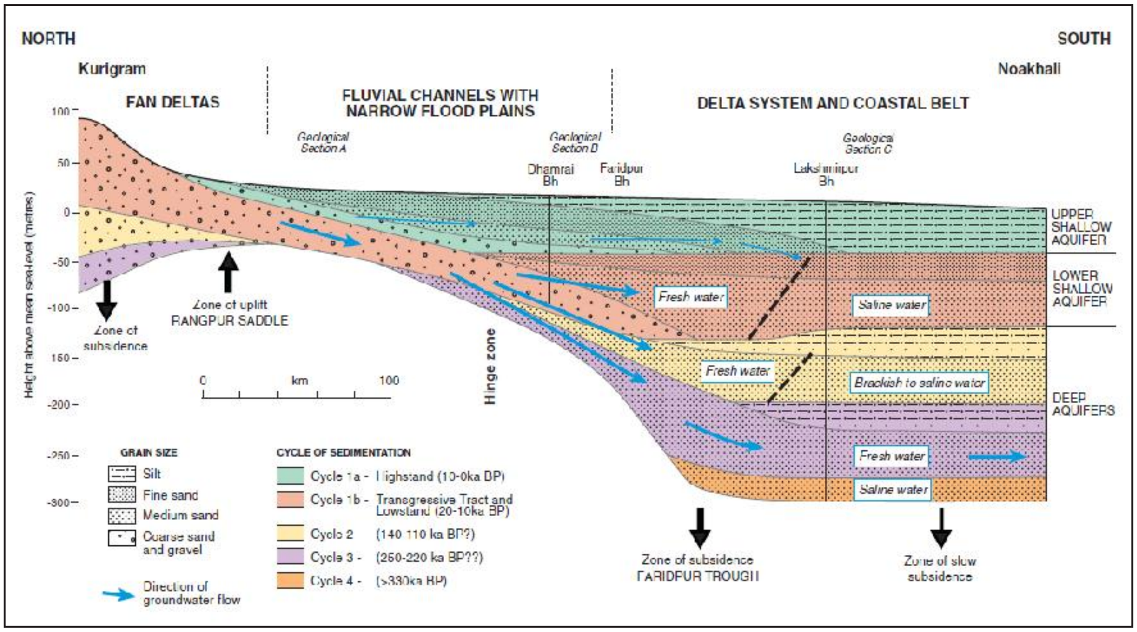

Figure 2.22: Hydrogeological cross-section of Bangladesh from north to south showing Quaternary aquifer system and groundwater flow pattern (DPHE-BGS 2001, in A. Zahid, 2015).

In the Chittagong region, groundwater development has less potential than the deltaic part of the country. The folds of the sedimentary strata developed from tectonics have made the geology of the area complex and consequently its hydrogeology as well. Thick beds of consolidated shale limit the vertical recharge of groundwater into the aquifer below. However, along the valley areas (synclines) deep groundwater is available within a depth range of 100 - 300 meters. Except some areas in the Khagrachari district, the groundwater table occurs at a greater depth below the ground surface. The primary source of natural groundwater recharge is direct rainfall (Hydrology, BWDB).

2.5.2. Groundwater development

To protect the population from water-borne diseases, millions of HTWs (<100m depth) have been installed in the shallow aquifers. Due to arsenic contamination, deeper exploration took place from the early 1990's onwards, resulting in the installation of deep Tubewells (DTWs) with an average depth of 100-250m. Different technologies are applied depending on the aquifer depth, as illustrated in the figure. Water supplies from deep tubewells however, frequently contain high levels of iron, manganese and chloride (Anwar Zahid, BWDB, 2014), limiting their development.

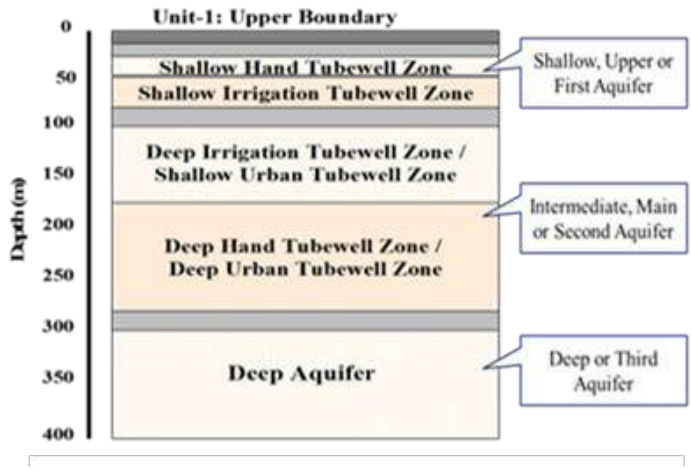

Figure 2.23: Groundwater development zones in Bangladesh (Zahid et al, 2014)

An even more massive development took place since the mid-1980s' with the development of groundwater for irrigation of (typically) Boro irrigation in the Rabi (dry) season. This development spurred much of the country's' agricultural development and present day self-sufficiency in food. A large part of this irrigation development took place in the North-west region. Out of the presently irrigated area of approximately 6 million ha, some 3 million ha is situated in the North-West region.

2.5.3. Decline of the groundwater table

The result of this intensive groundwater development has been a gradual (in the case of Dhaka area: rapid) decline of both pre-and post-monsoon groundwater table[6]. In intensively irrigated areas, groundwater level fluctuates from 5 and 15 meters below ground level, in some places even up to 23 meters during the dry peak irrigation season (excluding Dhaka City area). In Dhaka city area groundwater levels have fallen to 80m below ground level in the central part (see also Baseline Study Water Supply and Sanitation, sections 2.1, 2.3 and 5.1). In many areas, recharge does not keep up with abstraction and – especially in Dhaka city and selected areas in the North-West, especially the Barind Tract where a massive groundwater development has taken place since the 1980s'. Islam and Kanungoe (2005) estimated the long-term annual average recharge of 152.7 mm using water balance study and aquifer simulation modelling for the Barind area. This is notably less than the estimated recharge of at least one-third of the annual rainfall (i.e. 500 mm per annum) assumed by the Barind Multi-purpose Development Authority (BMDA) (Asaduzzaman and Rushton, 2006, quoted in S.K. Adhikar et al, 2013). As groundwater exploitation continues on the basis of one-third rainfall recharge hypothesis, Islam and Kanungoe (2005, quoted in in S.K. Adhikar et al, 2013), conclude that this is beyond the sustainable yield. In a recent research, Prof. Chowdhury Sarwar Jahan shows that net irrigation water requirement is between 1.5 and 5.5 times the useable recharge in the area[7] (Sustainability of Groundwater Resources in Barind Area, NW Bangladesh: An Integrated Approach of GIS and MEKESENS (Chowdhury Sarwar Jahan, undated). This reinforces the conclusion reached by Islam and Kanungoe (2005).

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[6] Actual groundwater abstraction is not being measured. There is no obligation for metering or licensing as yet

[7]. Based on long term monitoring and research by Rajshahi University, actual recharge is in the order of 8% of rainfall, as compared to the national average of 11%

A nation-wide comparison of the water tables from the 2004 and 2010 groundwater zoning, carried out by BADC, shows an increase of deep groundwater levels, as illustrated in the following table and figures (**Table 2.12** and **Figure 2.24, Figure 2.25, Figure 2.26**). A good indication can also be derived from the analysis carried out as part of the recent Integrated Water Resource Assessment (CSIRO, 2014), showing that both pre- and post-monsoon levels shows a declining trend (see Figure 2.25: Variation of pre-monsoon groundwater table, five year moving average

(CSIRO, 2014), and Figure 2.26: Variation of post-monsoon groundwater table, 5-year moving average

(CSIRO, 2014). Although further research is needed, it can be concluded that, at the present rate of abstraction and recharge, groundwater use in many areas is not sustainable.

Table 2.12: Area comparison groundwater tables 2004 - 2010 (BADC, 2011)

GW Level (m)	Area in 2004	Area in 2010	Difference	Percentage %
0,1 - 5,3	41958	35769	6189	14,75
5,3 - 7,6	31778	34671	2893	9,10
7,6 - 9,8	14441	13691	750	-5,19
9,8 - 11,3	5503	6849	1345	24,44
11,3 - 15,0	4812	5099	287	5,96
15,0 - 20,5	1464	3787	2323	158,73
20,5 - 26,0	200	452	251	125,47
26,0 - 35,5	112	209	96	85,77
35,5 - 60+	76	91	15	19,80
River	10856	10856	0	0
No Data	31836	31836	0	0
Char Land	4260	4260	0	0

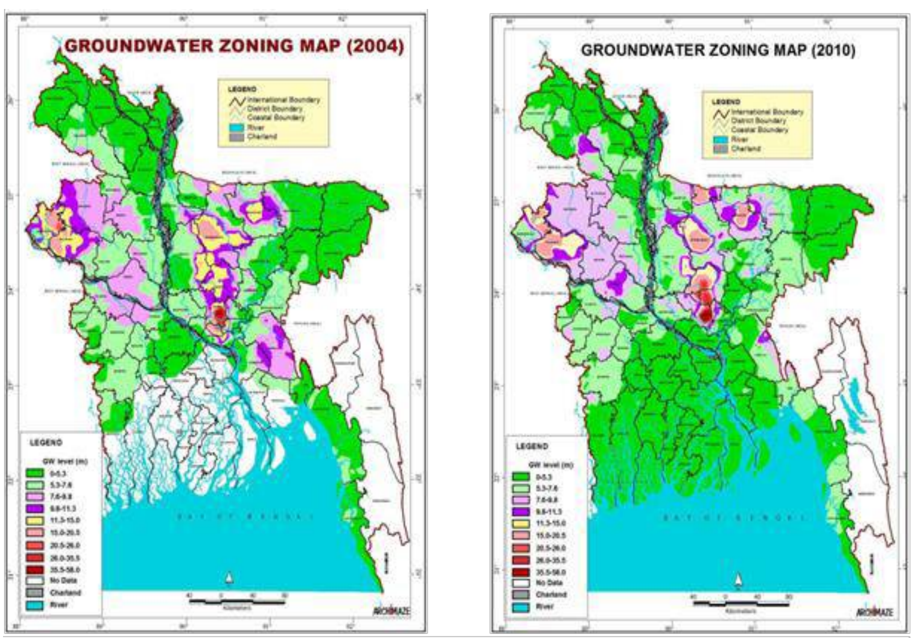

Figure 2.24: Groundwater Zoning Maps, 2004 and 2010 (BADC, 2011)

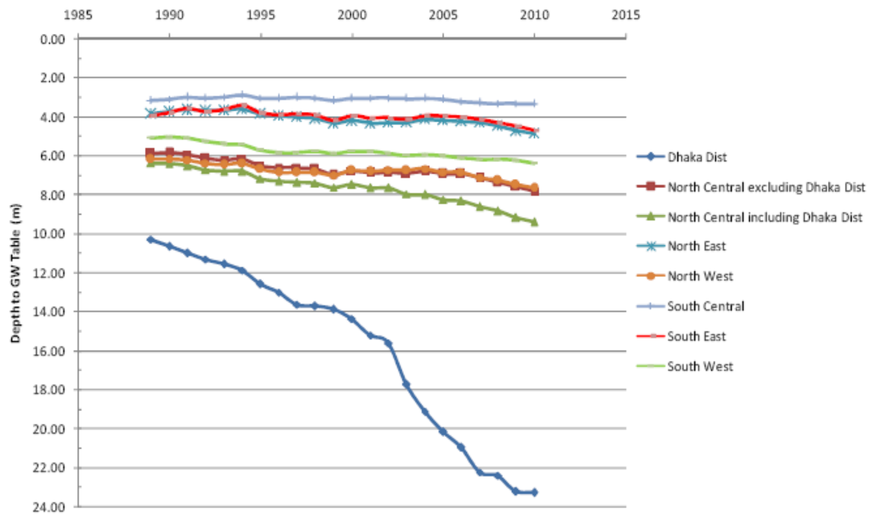

Figure 2.25: Variation of pre-monsoon groundwater table, five year moving average

(CSIRO, 2014)

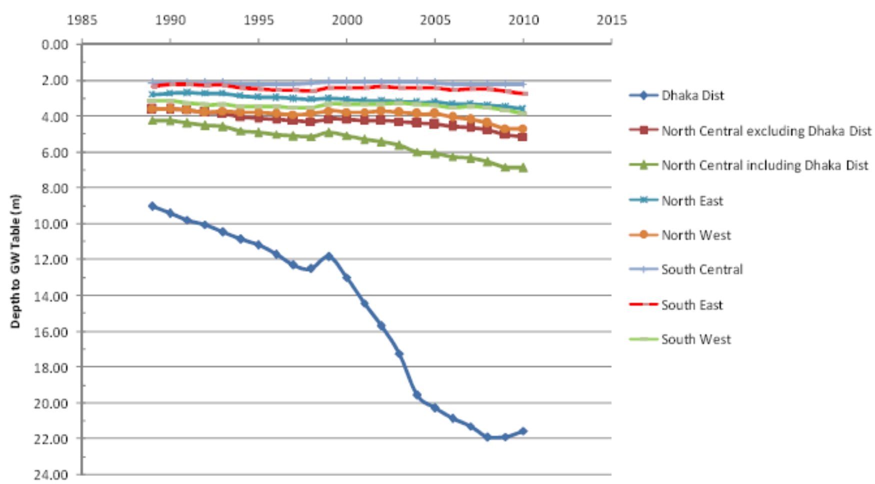

Figure 2.26: Variation of post-monsoon groundwater table, 5-year moving average
(CSIRO, 2014)

For Dhaka city area, where 85% of the water supply depends on groundwater, the trend is the clearest. The obvious reason is the explosive growth of the number of tubewells for drinking water supply, as illustrated below (**Table 2.13**). To keep up with the increasing demand, the drinking water authority, (Dhaka WASA), is presently developing new (deep) well fields about 20 km (Singair) outside of the city.

Table 2.13: Trend in Tubewell development in Dhaka, 1970 - 2014 (BWDB, 2014)

Year	1970	1980	1990	1995	2000	2005	2007	2014
Nos. of Tubewell	49	75	130	197	300	423	500	690
Withdrawal (Mm3/day)	0,18	0,217	0,516	0,767	1,2	1,5	2,0	2,5
Water Table (m)	0,5-10,5	0,5-9	6-22,5	12,5-32	19-41,5	19-54	19-67	24-71

Based on weekly monitoring records of groundwater levels throughout Bangladesh, Shamsudduha et al. (2011) show that shallow groundwater levels are declining at a high rate in recent time (1985 – 2005). Declining rates are highest (exceeding −0.5 m/year) in and around Dhaka City and Barind Tract region, and high (0 to −0.05 m/year) in areas south of the River Ganges. In the coastal areas, shallow groundwater levels are showing stable to slightly rising trends (0 to +0.1 m/year) over the same period (Shamshudda, 2011, in Zahid, 2015).

2.5.4. Groundwater Quality

Several groundwater quality monitoring studies (BWDB 2006, DPHE 1999) and the hydro-geological investigation by the British Geological Survey (1999) revealed that groundwater is generally fresh outside the coastal zone. However, 25% of the population was exposed to contamination exceeding Bangladesh standards in 2001 (NWMP, 2004). Coastal salinity and localized high dissolved iron in the alluvial aquifer was considered the major problem before detection of arsenic in groundwater. For more detailed information (on standards and health risks), see the Baseline Study on Water Supply and Sanitation. Surveys (Ahmed et al. 2004; Zahid et al. 2008) show that about 3 million tubewells, installed at shallow depths (10 to 50 m), discharge groundwater with arsenic concentrations above the Bangladesh drinking water standard of 50 µg/l. About 28 to 35 million Bangladeshis have been exposed to drinking water containing arsenic that exceeded the Bangladesh arsenic standard, and 46 to 57 million people have been exposed to drinking water containing arsenic that exceeded WHO arsenic standard (WHO, 2008) of 10 µg/L (DPHE-BGS 2001). In addition, some (deeper) aquifer systems are characterized by high manganese concentration and increasing trends of chloride are observed, even up to 16000 mg/l (**Figure 2.27**; see also Baseline Study Water Supply and Sanitation section 2.3).

Groundwater quality and availability is a clear gender issue. Women and girls are most often the primary users, providers and managers of water in their households and are the guardians of household hygiene. If a water system falls into disrepair, women travel long distances to meet their families' water needs. Consequently, women and girls benefit most when services are improved. At the end, the whole family - women, men, girls, boys and differently-able persons benefit in terms of access to quality water, better health, hygiene and sanitation (Rokeya Khatun, 2014). A recent study (Flanagan et al. 2012) reports that over the next 20 years Arsenic-related mortality in Bangladesh (1 of every 18 deaths) could lead to a loss of US $12,5 billion assuming a steady economic growth and an unchanged population exposure to As contamination.

The occurrence of arsenic is related to younger alluvial aquifers (Holocene age) containing finer sediments. The distribution of arsenic is highly variable both at a local and regional scale. Arsenic contamination above the permissible limit of 50 ppb is found in 61 out of 64 districts. Most of the contaminated aquifers are within 20 – 60 m depth (NWMP, 2004). Cost-effective means of arsenic removal have not yet emerged, although many technologies have been tested and developed[8].

Saline water is common in groundwater in the coastal belt and in the islands of Bangladesh and saline groundwater can be found up to 100 km inland. Local consumer tolerance to salinity is high. Bangladesh standards do not allow salinity higher than 600mg/l in drinking water (see also Baseline Study Water Supply and Sanitation sections 2.3 and 6.1). Studies demonstrate that most tolerant crops do not grow well when irrigated with water with salinity higher than 2500mg/l. Fourteen districts are affected by salinity in the coastal belt with an affected population of about 12 million people. The upconing of saline water due to well over-extraction in Bangladesh is still questioned. However several wells in the coastal as well as in inland areas have been abandoned due to salinization of the groundwater. There is no sharp boundary between fresh and saline groundwater zones,

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[8] "An Overview of Arsenic Removal Technologies in Bangladesh and India", M. Feroze Ahmed, Department of Civil Engineering, Bangladesh University of Engineering & Technology (BUET), Bangladesh

rather a patchy pattern of fresh and saline groundwater lenses distributed irregularly in areas close to the coast (Faneca Sanchez, 2015)[9], This sparse distribution of the saline water makes it impossible to talk about a homogeneous saline front, as illustrated in **Figure 2.28** and **Figure 2.29**.

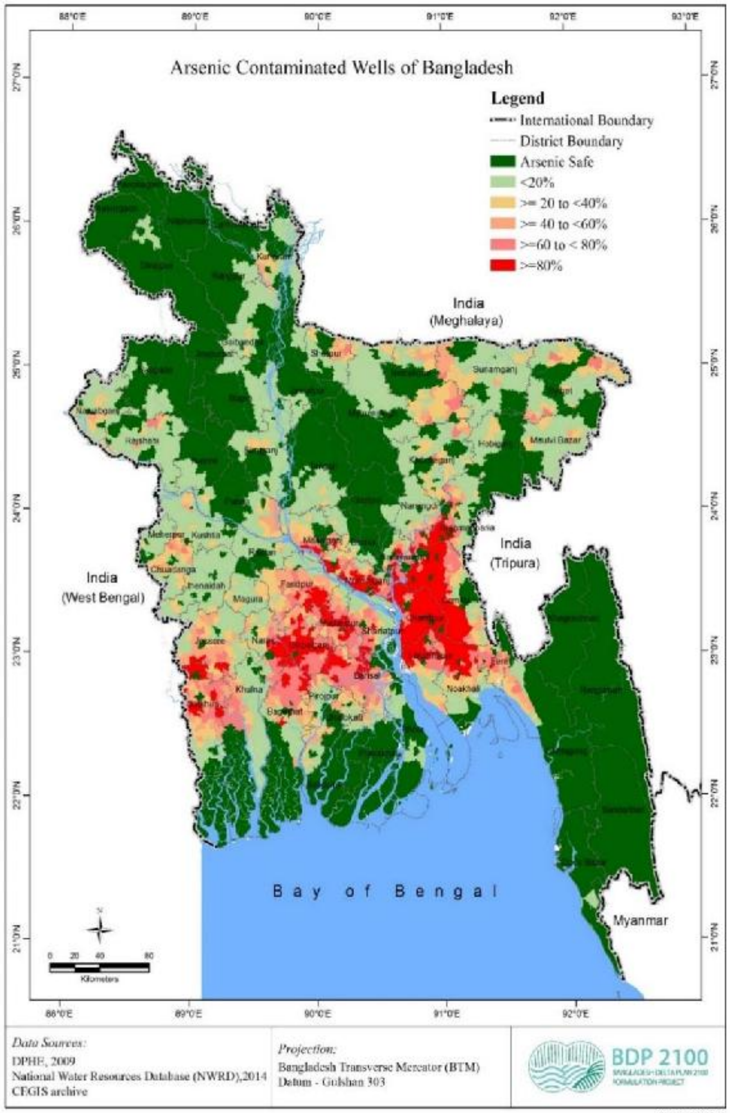

Figure 2.27: Percentage of Arsenic contaminated wells (CEGIS, from NWRD, 2014)

[9] https://publicwiki.deltares.nl/display/FRESHSALT/SWIBANGLA+Managing+saltwater+intrusion+impacts+in+Bangladesh

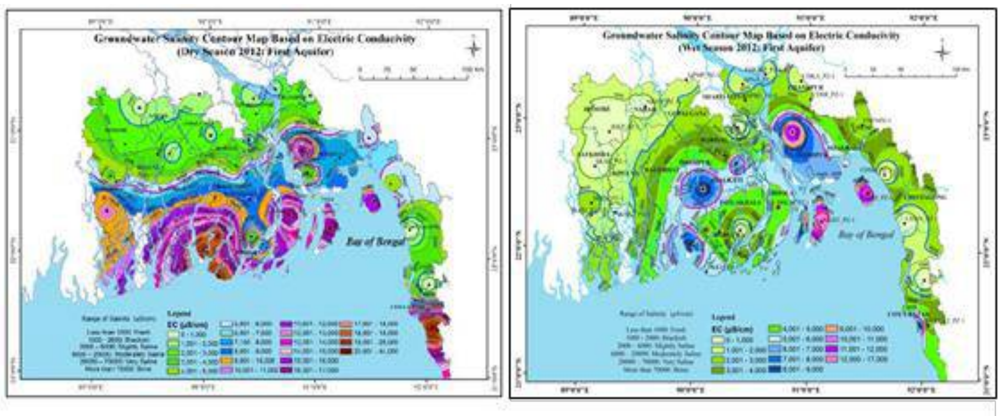

Figure 2.28: Groundwater EC Distribution, Shallow Aquifer, Dry (left) and Wet (right) Season 2012
(BWDB, 2013)

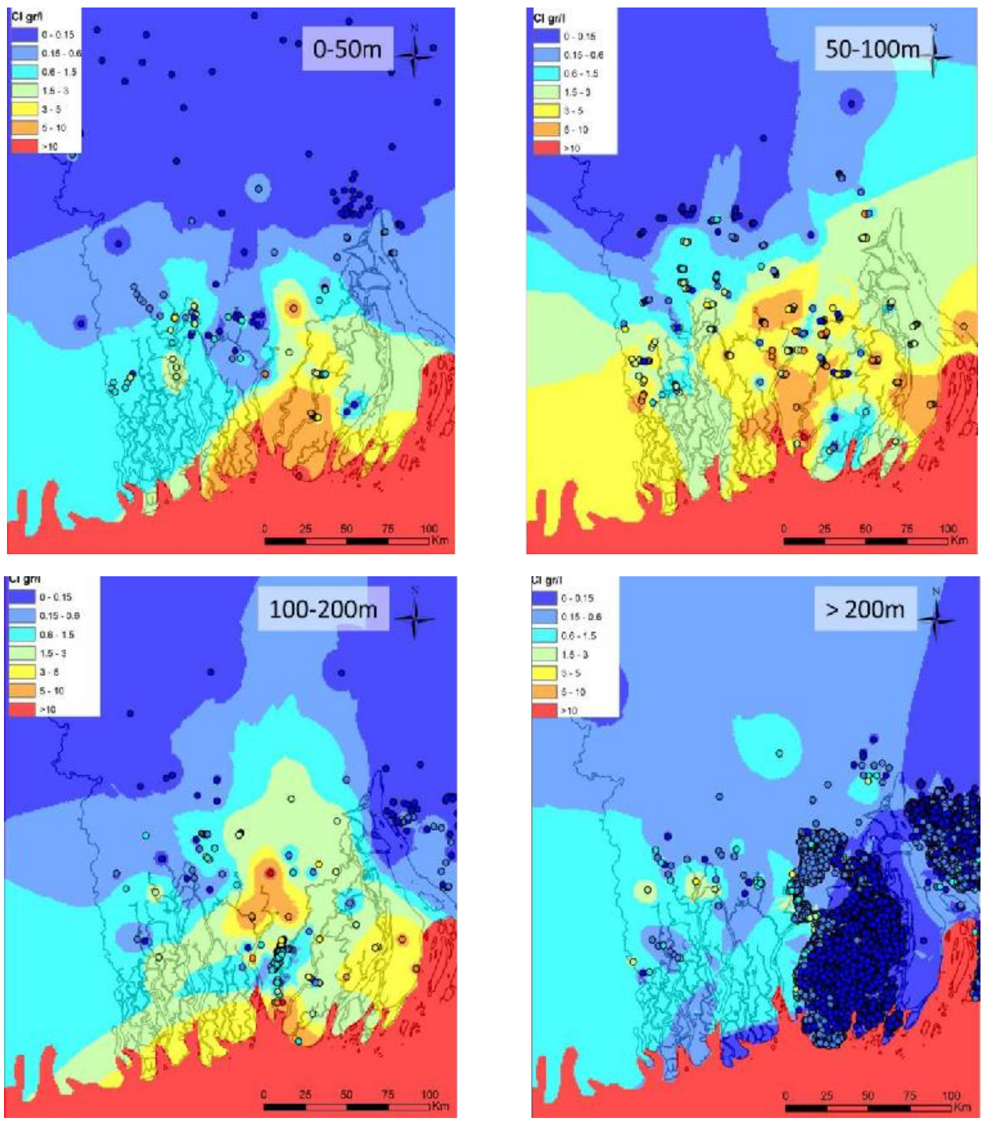

Figure 2.29: Salinity interpolation at varying depths (Deltares, 2014, BWDB and DPHE data)

It is expected that groundwater will remain the pre-eminent source of drinking water in future and, given the quality constraints mentioned previously, the exploration of deeper aquifer may be inevitable in the highly contaminated coastal area. Deep aquifers have already been explored for drinking water purpose in saline prone areas (i.e. the DPHE-DANIDA Urban Water and Sanitation Project) with deep tubewells in the eastern coastal regions currently providing fresh potable water. The deep alluvial aquifer in the coastal area occurs within an average depth range of 250m - 360m. The hydrogeological properties and the characteristics of this aquifer are however not yet well known (see also Baseline Study Coast section 2.3).

Groundwater resources are becoming increasingly polluted by industrial activities. The Hazaribagh leather processing zone of Dhaka city is an example of the danger of future aquifer contamination if pollution from the approximately 185 tanneries is not abated. Research by Zahid et al (2006) showed that investigated trace elements of all the groundwater samples (65-90 m depth) were found within DoE and WHO limits. However, previous research indicates that shallow groundwater (10-20 m) of Hazaribagh area has already been affected by high Cr, Pb and other heavy metals. The presence of heavy metals in groundwater, even in low concentrations, and higher concentrations of Na, Ca, Mg, NH4, Cl, SO4 compared to the average concentrations of the surrounding areas has been providing evidence of release of some of these heavy metals and increase of ions due to industrial activities in the area. Recent data on groundwater quality show elevated and increasing levels of dissolved solids, both in the upper aquifer (5 to 200 m below surface) and the lower (below 200 m) aquifer (DWASA and IWM, 2005 unpublished). Close monitoring and further research – as well as pollution abatement strategies for the industrial activities – is needed to prevent irreparable and costly damage to the aquifers of this kind.

2.5.5. Surface-groundwater interactions

Surface and groundwater interactions are an important feature of water resource management in Bangladesh. Analysis of groundwater level and river-stage hydrographs (Shamsudduha et al. 2011) reveals that water levels in almost all river channels rise above groundwater levels in adjacent aquifers during the monsoon season (May–September); indirect recharge is restricted to lateral river-bank infiltration during the early monsoon time (April–June). Shallow aquifers adjacent to the River Brahmaputra mostly experience greater indirect groundwater recharge (Zahid, 2015).

Research by Shamshudda (2011) indicates that mean recharge in Bangladesh has increased from 132 mm/year over a period from 1975 to 1980 to approximately 190 mm/year for the period 2002–2007, as illustrated by **Figure 2.30**. A key factor in explaining the increased recharge is the increased groundwater withdrawals country-wide. Regional variations are large however, as discussed in the supplementary study 'Groundwater Management Aspects in Bangladesh' by Anwar Zahid (2015) and by Prof. Chowdhury Sarwar Jahan in 'Mapping of Groundwater Recharge Potential in Bangladesh' (undated), and illustrated in Figure 29 (Left: Potential Recharge using a water-balance method - UNDP 1982, Right: Usable Recharge using finite-difference recharge models - 1991).

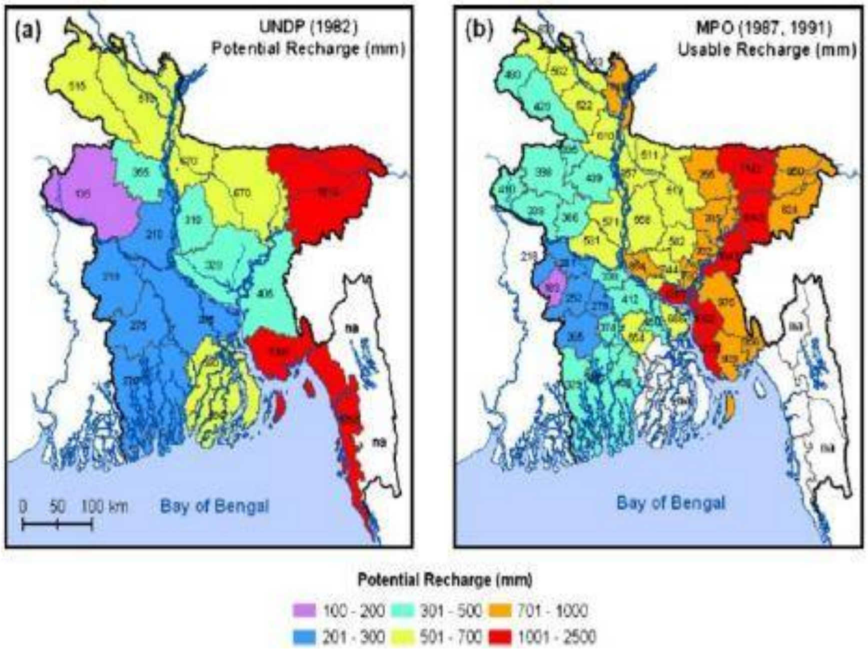

Figure 2.30: Recharge potential in Bangladesh

The figure below (**Figure 2.31**) illustrates the recharge from the Jamuna River to the aquifer from May to October, with some discharge from the aquifer back to the river during the dry season. These interactions are however not well understood yet and constitute a knowledge gap.

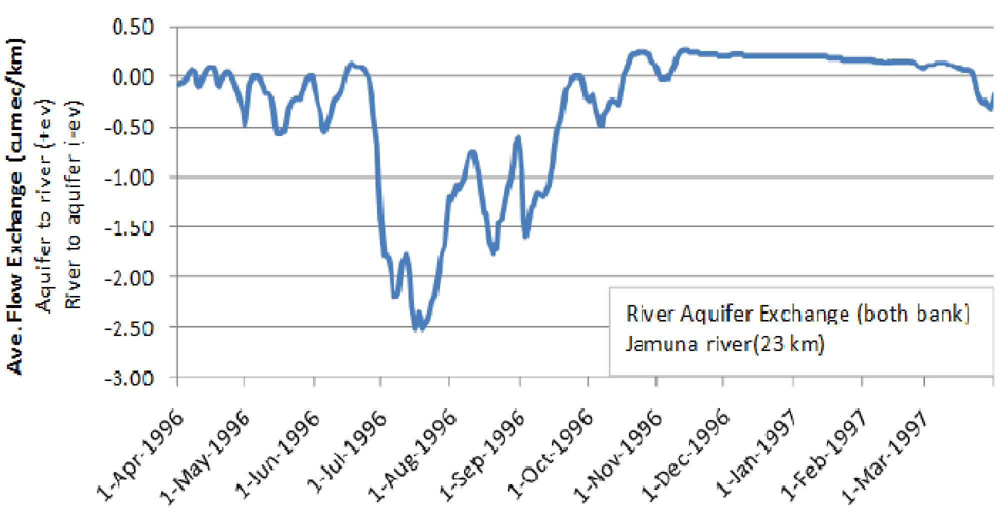

Figure 2.31: Simulated exchange between the Jamuna and the adjacent aquifer in 1996
Source: CSIRO, 2014

Figure 2.31 (next page) shows groundwater recharge for pre-developed groundwater-fed irrigation period (1975–1980), post-developed groundwater-fed irrigation period (2002–2007) and long-term mean recharge period (1985–2007)

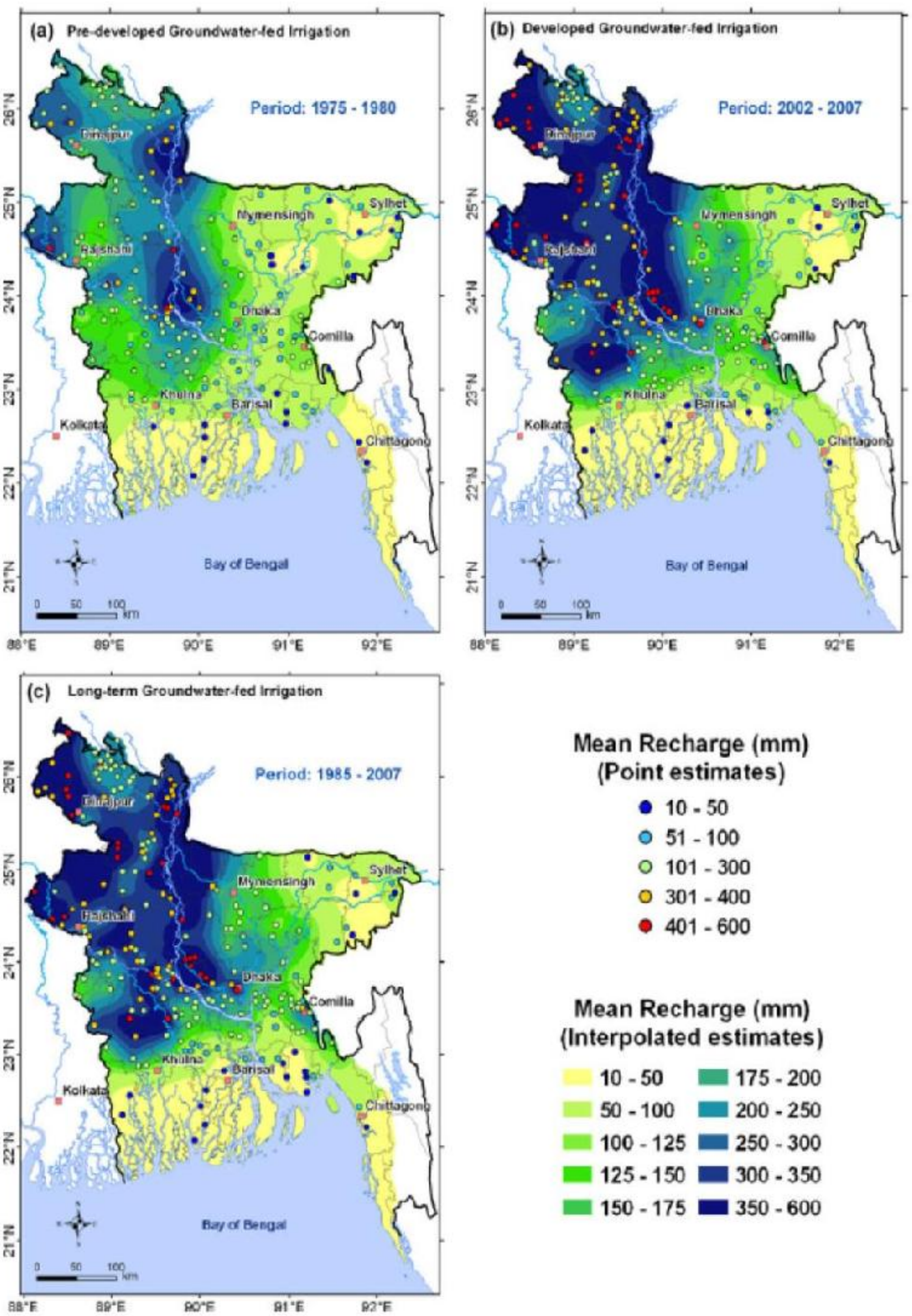

Figure 2.32: Groundwater recharge for pre-developed groundwater-fed irrigation period (1975–1980), post-developed groundwater-fed irrigation period (2002–2007), and long-term mean recharge period (1985–2007)

Source; Shamsudduha et al. 2011, in A. Zahid, 2015

3. Water Resource Development

3.1. Flood Control and Drainage scheme development

In response to a number of disastrous floods in the 1950s', the first master plan for water resource development was initiated in 1964 (carried out by the American company IECO). The plan envisaged the creation of 58 large flood protection and drainage projects covering some 5.8 million ha of land. The 1972 Land and Water Study, carried out by the World Bank, placed greater emphasis on rapid implementation of smaller schemes in areas with a relatively low flooding depth. Projects such as the Early Implementation Projects (EIP) were formulated and an impressive expansion of protected areas took place. Bangladesh Water Development Board (BWDB) was formed as a separate entity and this organization came to play a central part in the development of FCD projects. To date, more than 700 projects have been developed by BWDB (detail breakdown in **Table 3.1**). By excluding flood waters from an area, the basic function of FCD infrastructure for agriculture is to convert F1, F2 or F3 land to a shallower flood phase, which facilitates conversion from Broadcast Aman to Transplanted Aman and from Local to High Yielding Varieties. As a result, yields increase. Another benefit in the Inland Areas is to protect the Boro Rice crop from early flash floods, mostly in the North-Eastern region. For the Coastal Areas the main benefit lies in the exclusion of saline water.

Positive and negative impacts

According to Liakath Ali (2002), FCD schemes have contributed to a raise in rice production of some 35% inside the FCD scheme areas. FCD development has thus contributed to the increase in agricultural productivity in the country, as illustrated below (**Figure 3.1**). This increase should however also be attributed to the development of (minor) irrigation, as will be discussed later.

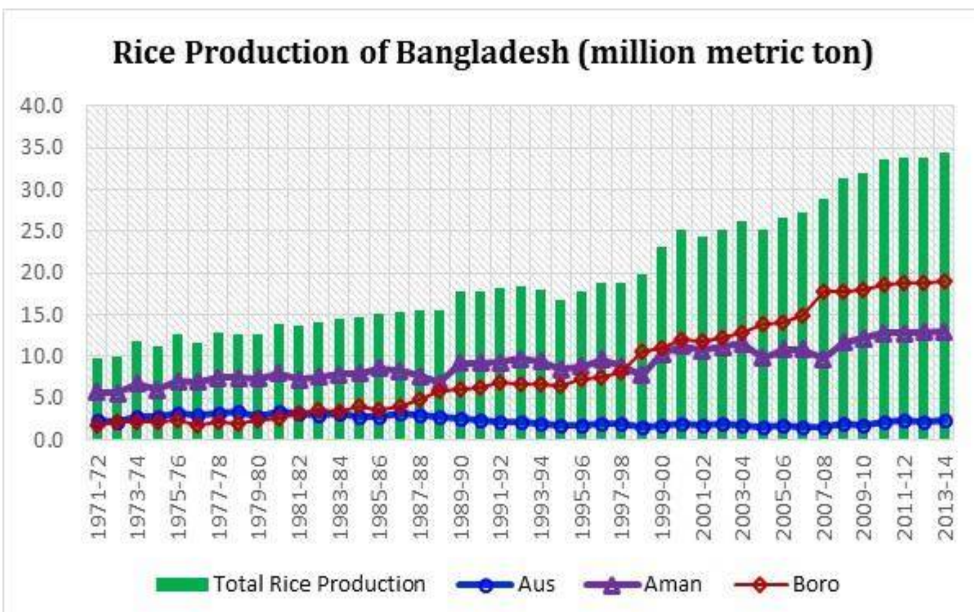

Figure 3.1: Increase in rice production in Bangladesh

Source: 1971– 2010 presentation by BWDB, World Environmental Day, 2012

An overview of developed (FCDI) schemes by BWDB is provided in **Figure 3.2** (map) on next page.

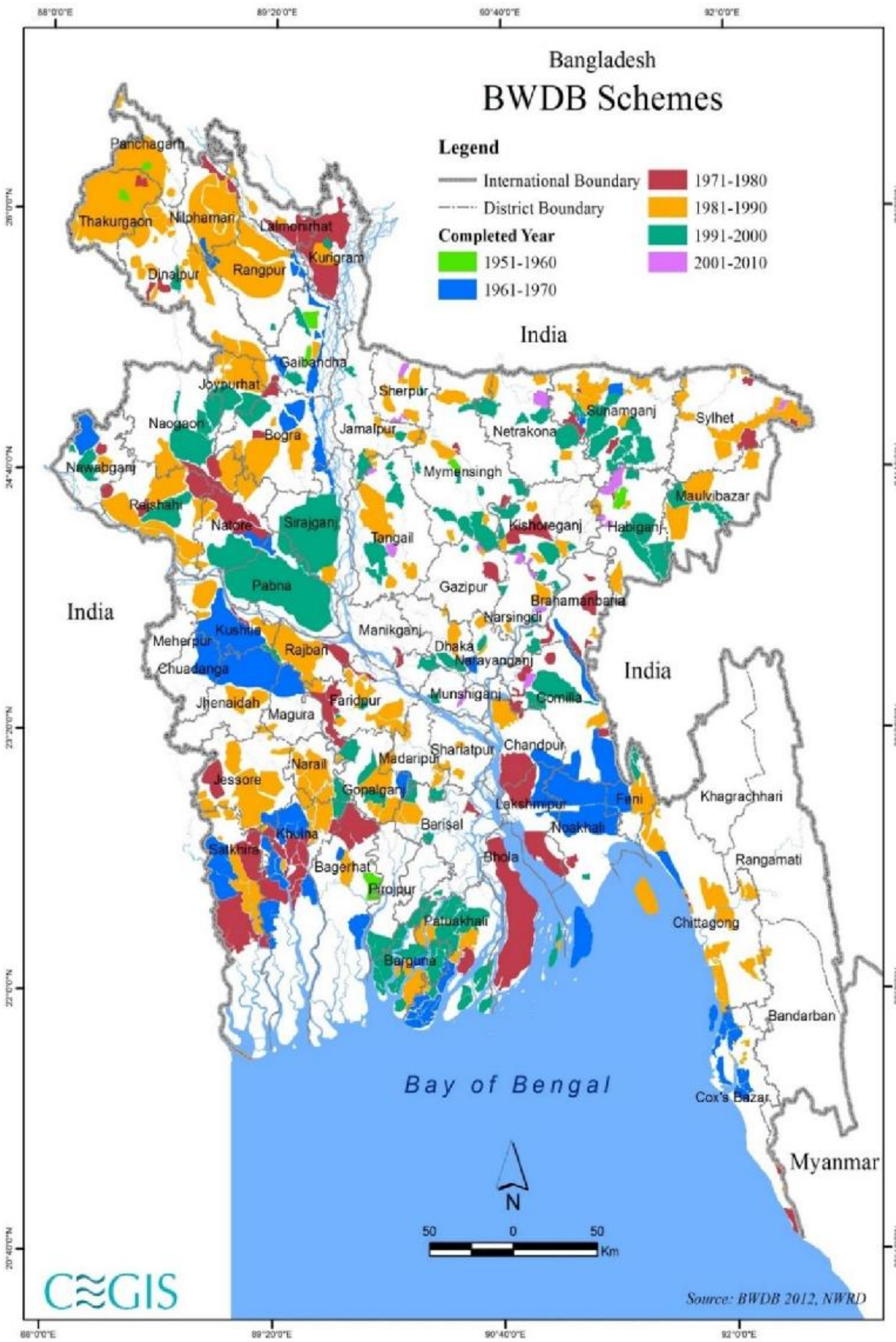

Figure 3.2: Overview of BWDB developed schemes, 1951 – 2010

Source: BWDB, from the NWRD 2012

FCDI (or polder) development has however not been only positive. In the coastal areas, polder development has, along with other factors such as a decreased fresh water flow to the Ganges Dependent Area (GDA), contributed to increased *waterlogging inside the polders* and, by decreasing the tidal flow, *siltation of river channels* (see also Baseline Study on Coast and Polder, section 2.3) Other negative impacts include the *interruption of fish migration routes*, affecting capture fisheries, and the *raising of flood levels outside the embanked areas.* These impacts should be quantified however and require a more integrated, updated and in-depth (economic) analysis. Monitoring data of the DoF indicate that, in the period 1983 – 1989, from a base of almost 500,000 tons per year, capture fisheries from river, beels and floodplains has decreased by 4000 tons annually. However, culture fisheries output rose with 48,000 tons annually in the same period, making up for the loss of inland capture fisheries[10]. Regarding the raising of flood levels outside the embanked areas, no systematic monitoring has been undertaken, and one has to rely on a 1998 study by the Bangladesh University of Engineering & Technology (BUET). This study in 20 *Thanas* (now Upazilas) showed no significant correlation between the percentage increase in FCD coverage and the percentage increase in Aman production on a Thana level between 1964 and 1993[11].

The most common type of projects is the FCD, FCDI and CFCD, together constituting some 80% of all developed BDWB projects; an overview of such projects up to 2002 is presented on next page (**Table 3.1**).

In addition to the FCDI projects, the country avails of 4 barrages across the rivers Teesta, Tangon, Buri-Teesta and Manu, which are used as diversion structures for irrigation purposes, and one large dam: the Kaptai Dam in the Chittagong Hill tracts. The Kaptai dam, with a total storage capacity of is used primarily for hydroelectric power generation. The Kaptai dam is that largest dam in South Asia outside of China, with a total storage capacity of 20.3 bcm (FAO, 2011). At an estimated evaporation rate of 1200 mm per year, some 1.29 bcm of water is evaporated from the reservoir per year (FAO Aquastat 2011). Bangladesh constructed a barrage on the Teesta River in 1990 to provide irrigation water for crop production in the Teesta Barrage Project area. At an earlier stage, India constructed the Farakka Barrage at Gajoldoba upstream of the Teesta barrage. The Teesta barrage started operation with limited conveyance infrastructure in 1993, with a further expansion in 1998 (Md. Nurul Islam et al, 2003). Since then, two main dams have been developed in the Indian part of the Teesta; the Teesta -V dam, completed in 2007 has been the largest project so far. The Teesta V dam was developed to generate hydroelectric power (510 MW) and assist flood control. The second dam is the Rangit III hydroelectric project, completed in 2000 on the greater Rangit River, a tributary of Teesta River. The other three (much smaller) completed projects are the Lower Lagyap, Upper Rongni Chhu and Mayang Chhu projects.

Table 3.1: Distribution BWDB Projects (Source : BDP2100 team)

	Project Size (Lakh Ha)				
	Small	**Medium**	**Large**	**Very Large**	**Total**
Type of Projects	**<0,01**	**0,01-0,05**	**0,05-0,15**	**0,15 Above**	
Irrigation					
i) Numbers of Projects	70	20	7	11	108
ii) Area in Ha	0,24	0,44	0,54	5,50	6,72
Drainage					
i) Numbers of Projects	55	59	11	8	133

[10] In: Controlling or Living with Floods in Bangladesh, Agriculture & Rural Development Working Paper 10, World Bank, 2003

[11] In: Macro Impact of Flood Control Projects on Aman Rice Production', BUET, 1999, quoted in: Ahmed, Imtiaz (editor), Living with Floods, an exercise in alternatives, UPL, Dhaka, 1999

	Project Size (Lakh Ha)				
	Small	**Medium**	**Large**	**Very Large**	**Total**
Type of Projects	**<0,01**	**0,01-0,05**	**0,05-0,15**	**0,15 Above**	
ii) Area in Ha	0,31	1,40	0,78	6,29	8,78
Drainage and Irrigation					
i) Numbers of Projects	1	9	1	3	14
ii) Area in Ha	0,00	0,21	0,07	4,06	4,34
Flood Control and Drainage					
i) Numbers of Projects	30	49	35	31	145
ii) Area in Ha	0,18	1,31	3,12	14,02	18,63
Flood Control Drainage and Irrigation					
i) Numbers of Projects	9	13	14	24	60
ii) Area in Ha	0,05	0,37	1,20	20,48	22,09
Submersible Flood Control and Drainage					
i) Numbers of Projects	2	12	5	6	25
ii) Area in Ha	0,01	0,43	0,30	1,23	1,98
Submersible Flood Control Drainage and Irrigation					
i) Numbers of Projects		2			2
ii) Area in Ha		0,07			0,07
Coastal Flood Control and Drainage					
i) Numbers of Projects	17	42	27	17	103
ii) Area in Ha	0,10	1,31	2,58	6,01	10,00
Coastal Flood Control Drainage and Irrigation					
i) Numbers of Projects	1	3	2		6
ii) Area in Ha	0,01	0,07	0,20		0,28
Shrimp Culture Polder					
i) Numbers of Projects		2	3		5
ii) Area in Ha		0,07	0,26		0,32
Total					
Total i) Numbers of Projects	**185**	**211**	**105**	**100**	**601**
Total ii) Area	**0,89**	**5,68**	**9,05**	**57,60**	**73,22**
Percentage-wise Distribution					
i) Number of Projects	30,78%	35,11%	17,47%	16,64%	100%
ii) Area in Ha	1,22%	7,75%	12,36%	78,67%	100%
Feasibility Study					
i) Numbers of Projects					61
Protection					
i) Numbers of Projects					49
Town Protection					
i) Numbers of Projects					59
Grand Total of Projects					**770**

LGED has, in its *Small Scale Water Resources Development Sector Projects* (phase I, II and III, on-going), has developed over 500 'sub-projects' aimed at improved water resource management in FCD(I) projects. As per the

NWPo, LGED focuses on project development of areas below 1000 hectares, which may be part of larger BWDB developed FCD projects. In terms of technical set-up, many similarities exist between the BWDB and LGED implemented projects. LGED played a pioneering role in the development of a participatory approach to project development and pioneered the formation and development of the Water Management Cooperative Association (WMCA) and close involvement of Local Government Institutions (LGIs) in project identification, feasibility, design, implementation and Operation & Maintenance (O&M). In addition, the project approach stressed the representation of both women and men in all representative bodies of the WMCA, with 2 dedicated seats for women on the Executive Committee of the WMCA. The project is now in its third phase, which includes the improvement, and in selected cases rehabilitation, of existing as well as the development of new projects[12].

3.2. Irrigation development

Irrigation in Bangladesh is often categorised in *Major* and *Minor Irrigation*. Major irrigation typically covers large (surface) irrigation projects, developed by the BWDB. Minor irrigation covers the remainder of the irrigation types, comprising both traditional surface irrigation from canals and rivers using traditional lifting technologies and pumped irrigation from surface and groundwater. At present, irrigation is practised for boro rice (71%) and wheat (9%), which together occupy 80% of the irrigated land (FAO, 2015). The total irrigable area in the country is 7.56 million ha according to BADC (2014) and 6,933 million ha according to FAO. Using the FAO estimate, this amounts to 79% of the cultivable and 81.1% of the cultivated area.

Minor irrigation projects fall under the jurisdiction of the Ministry of Agriculture (i.e. BADC) and small-scale surface irrigation under the Ministry of Local Government, Rural Development and Cooperatives (i.e. LGED). Major irrigation projects are the responsibility of the Ministry of Water Resources (i.e., the BWDB).

Minor irrigation

Minor irrigation was introduced in Bangladesh in the early 1960s' using Low Lift Pumps (LLP). A total of 1555 LLP were operated by BADC in 1961. From then on, the number grew spectacularly. Where minor irrigation covered approximately 1.5 million ha in 1982, the figure rose to 2.6 million ha in 1990 to nearly 4 million ha in 1998, 5 million ha in 2010 and, according to BADC and BWDB, some 6 million ha at present (BADC, BWDB, 2014). This figure is notably higher than the FAO estimate of 2010 of 5.41 million ha (Aquastat, based on BBS data for 2009) and lower than the BBS estimate of 2013 of 6,974 million ha (BBS, Statistical Yearbook 2013). The latter includes some 0.34 million ha of traditional (canal) irrigation (BBS, 2013).

The nature of irrigation soon changed to groundwater abstraction in the late 1980s', initially through Deep Tube Wells (DTWs), followed by introduction of Shallow Tube Wells (STW), driven by surface mounted centrifugal pumps. Much of this growth was driven by private, local initiatives, and the publicly managed groundwater based Barind Irrigation Project (BIP). The BIP covers parts of seven North-Western districts, namely Bogra, Dinajpur, Joypurhat, Naogaon, Pabna, Rajshahi, and Rangpur under Rajshahi division. The project was carried out by the Barind Multipurpose Development Authority (BMDA). By 2000, some 6,000 deep tube wells and 66,000 shallow tube wells were installed under the BIP (Adhikary et al, 2013).

The enormous growth in groundwater irrigated area is illustrated in the figure below (**Figure 3.3**). The growth of DTW and STW is illustrated in **Figure 3.4** and **Figure 3.5** respectively.

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[12] Project Final Report, July 2010, SSWRDSP

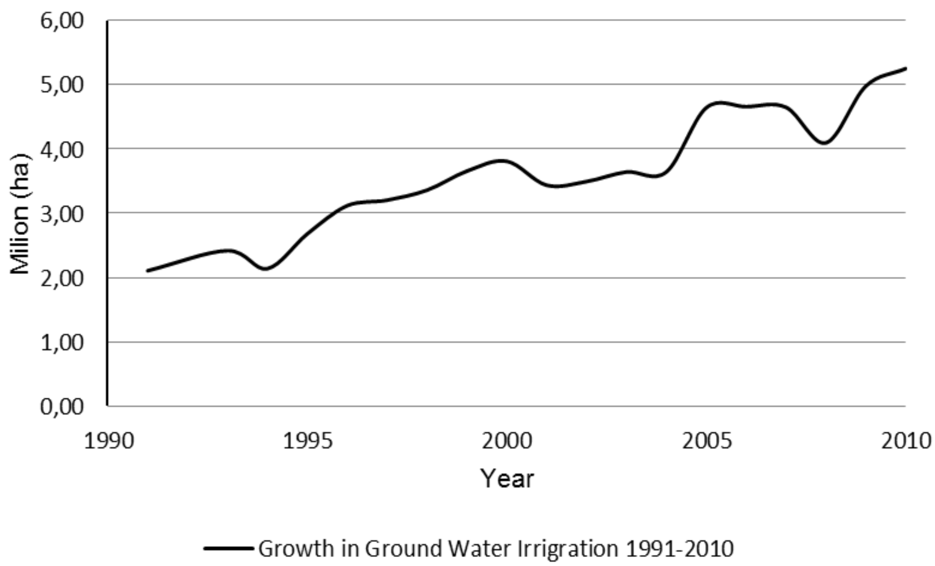

Figure 3.3: Growth in groundwater irrigation 1991 – 2010

Source: BADC, NWRD)

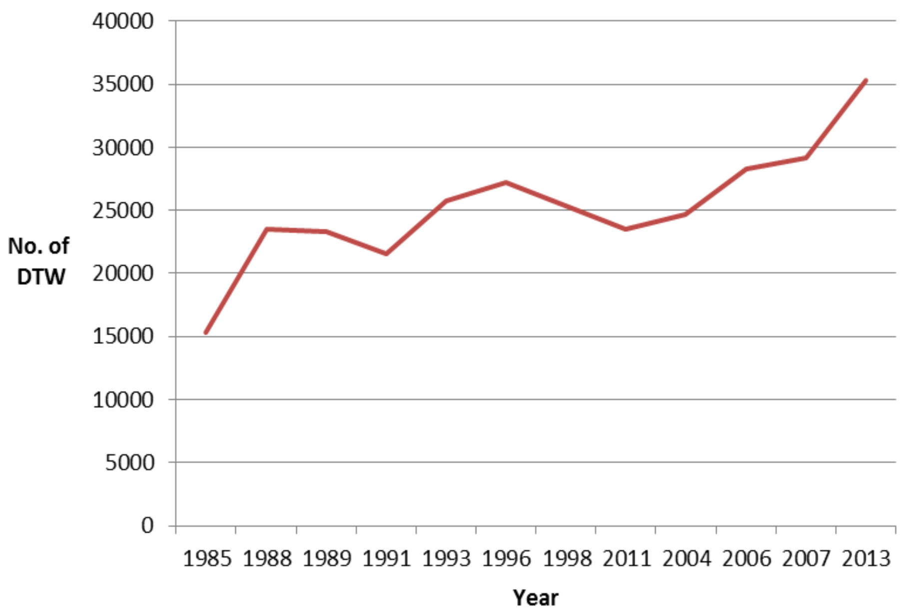

Figure 3.4: Growth in DTWs in Bangladesh (1985 – 2013)

Source: A. Zahid, 2015, compiled from BADC, MPO/WARPO, AST/DAE, NMIDP

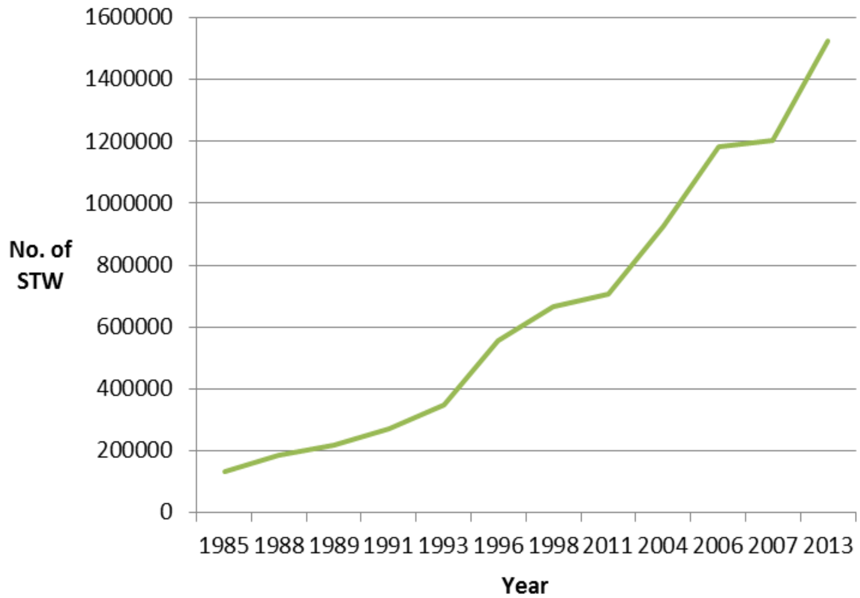

Figure 3.5: Growth in STWs in Bangladesh (1985 – 2013)
Source: A. Zahid, 2015, compiled from BADC, MPO/WARPO, AST/DAE, NMIDP

Part of the irrigation expansion was made possible because of the existence of FCD infrastructure, essentially by providing increased security and by allowing for increased retention and inlet of irrigation water ('flushing'). Irrigation inside FCD areas is typically drawn from surface water in the *khals* or *beels* by means of LLPs. Often, the lifting device belongs to an individual farmer, whilst the conveyance canals are typically constructed by groups of farmers.

Major irrigation

Major irrigation, which is managed by the BWDB, covered some 0.30 million ha. A summary of the key characteristics of the largest major irrigation projects in Bangladesh is provided in **Table 3.2** below.

Table 3.2: List of key major (surface) irrigation projects in Bangladesh
Source: ***http://www.bwdb.gov.bd***

Name	Location (district and HR)	Area
Ganges-Kobadak Irrigation Project	Kushtia, Chuadanga, Jhenaidaha, Magura (NW)	197486 ha (Phase-I: 84986 ha, Phase-II: 112500 ha)
Chandpur Irrigation Project	Chandpur and Lakshmipur (SE)	54036 ha (of which 24291 ha is equipped for irrigation)
Meghna-Dhonagoda Project	Chandpur (SE)	19021 ha (of which 14400 ha is equipped for irrigation)
Manu River Project	Maulvi Bazar (NE)	22580 ha (of which 12090 ha is equipped for irrigation)
Pabna Irrigation Project	Pabna (NW)	196680 ha (of which 21862 ha are equipped for irrigation)
Gumti Project	Comilla (SE)	37440 ha (of which 11000 ha is equipped for irrigation)
Teesta Barrage Project	Rangpur, Lalmonirhat and Nilphamari (NW)	132000 ha (111406 ha equipped for supplementary irrigation)

The distribution of the various types of irrigation modes is illustrated below in tabular (**Table 3.3**), and graphic form (**Figure 3.6**).

Table 3.3: Distribution of irrigation modes in Bangladesh (BADC, 2007)

Irrigation Mode	No. of Equipment	Area Irrigated (ha)	% of total Irrigated Area (ha)	Area Irrigated/ Equipment (ha)
A. Ground water irrigation				
Deep tube well irrigation	29177	725258	14,85	24,86
Shallow tube well irrigation	1202728	3196127	65,46	2,66
Manual, traditional method, (don, dug well, treadle pump, rower pump, hand tube well)	-	14403	0,29	-
Sub Total	1231905	3935788	80,60	-
B. Surface water irrigation				
Low lift pump irrigation	107293	810027	16,59	7,55
Gravity flow irrigation	-	137064	2,81	-
Sub Total	107293	947091	19,40	-
Grand Total	1339198	4882879	100	-

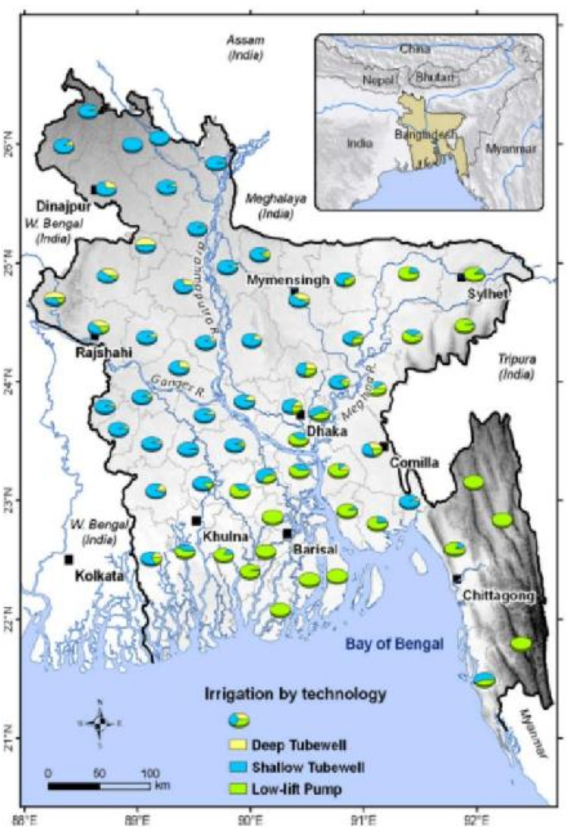

Figure 3.6: Relative proportion of dry season irrigation pumping technologies in Bangladesh Source: Shamsudduha et al. 2011, in A. Zahid, 2015

3.3. Water Use and Demand

3.3.1. Introduction

In this section, key water use and water needs or demands in Bangladesh are discussed. Water demands include the agriculture and industry sector but also cover environmental needs, fisheries and in-stream demands. According to the National Water Policy (NWPo) and the new (2013) Water Act, the priorities for water resource allocation in the country are, in order of importance: water supply, then in-stream needs, and finally irrigation needs. A comprehensive and sound overview of total demands, using a common set of baseline data, assumptions and definitions, has not been developed in Bangladesh yet and this section necessarily provides an approximation only. Given the expected future increase in water demand and water scarcity in the dry season, such a comprehensive demand analysis is however urgently required. This analysis will also support the Government's intention to develop Water Allocation Plans (WAP) for water stressed areas, as mentioned in the new 2013 Water Act. WAPs should take into account both water quantity and quality, for all water usages and water system functions.

According to FAO (2013), overall water withdrawals total 36 bcm, composed of 32 bcm for irrigation and 4 bcm for domestic and industrial purposes. Of the volume withdrawn for irrigation, 28 bcm comes from groundwater. These figures are presented below, side by side with CSIRO estimates of 2014.

Table 3.4: Water demand per sector (CSIRO, 2014 & FAO, 2013)

Water demand	**Source**			**%**
	CSIRO regional water balance	**CSIRO supplementary reports**	**FAO**	
total			36	
Irrigation use	25 (excl EH)	33	315	
From SW	6		662	21%
From GW	19		249	79%
Forest	29			
Fisheries	52			
Fisheries capture	31			
Fisheries open water	21			
Domestic		27	36	
Industry		008	08	

3.3.2. Agriculture

The agriculture sector remains the largest water user by far, accounting for some 90% of all water use, whereby approximately 80% of irrigation is from groundwater. Rice is the main crop, covering some 80% of the total cropped area. The other main irrigated crops are wheat, vegetables and potatoes.

Approximately 70% of the net cropped area is under Aman production. For Boro and Aus, these figures are 50% and 13% respectively. The growth in irrigation is slowing down and may have reached its peak due to physical and infrastructural conditions, such as the declining of the groundwater table in key irrigated areas in the North-west and, to a lesser degree, the North-central regions. It is also Government policy to stimulate the conversion of Boro rice cultivation to Wheat and other less water demanding crops in these areas.

Based on food demand modelling (using the ARIMA model), the IWMI estimates the annual consumptive water demand (CWU) for rice production to increase to 67.9 bcm for 2020 and 71.7 bcm for 2030, from the current 2010 level of 63.0 bcm. Out of this CWU, irrigation is needed almost exclusively for Boro rice cultivation, amounting to 20.9 bcm and 24.5 bcm for 2020 and 2030, up from the 2010 level of 16.5 bcm. Rice production accounts for 93% of the total CWU and 90% of the total irrigation CWU (IWMI Research Report 158 'Water for Food in Bangladesh: Outlook to 2030', Upali A. Amarasinghe, Bharat R. Sharma, Lal Muthuwatta and Zahirul Haque Khan). These estimates are lower than the FAO estimates in AQUASTAT.

Another factor in projecting future demand is the reduction of the agricultural land, of which estimates vary between 0.5 and 1 % per year at the national level. CSIRO (2014) drawing from statistics of the BBS, estimates the annual decline of agricultural land 30,000 ha per year, by conversion to urban land use. There are huge differences in the spatial distribution however, with the North-central region showing the highest level of decline.

Climate change has a much smaller impact on future demand than the increased food demand outlined above, which is largely driven by population increase. Based on the application of 4 different climate scenarios (2030 average and dry and 2050 average and dry), and considering the existing cropping pattern, Mainuddin M et al (2013), conclude that due to climate change, irrigation water demand is projected to increase by less than 1% for the 2030 average condition to the maximum of 3% for the 2050 dry condition, as illustrated in the figure below (**Figure 3.7**). The maximum additional irrigation water requirements at country level will be less than 1 bcm for the 2050 dry climate scenario (Mainuddin M, 2013). This demand is heavily dominated by Boro rice.

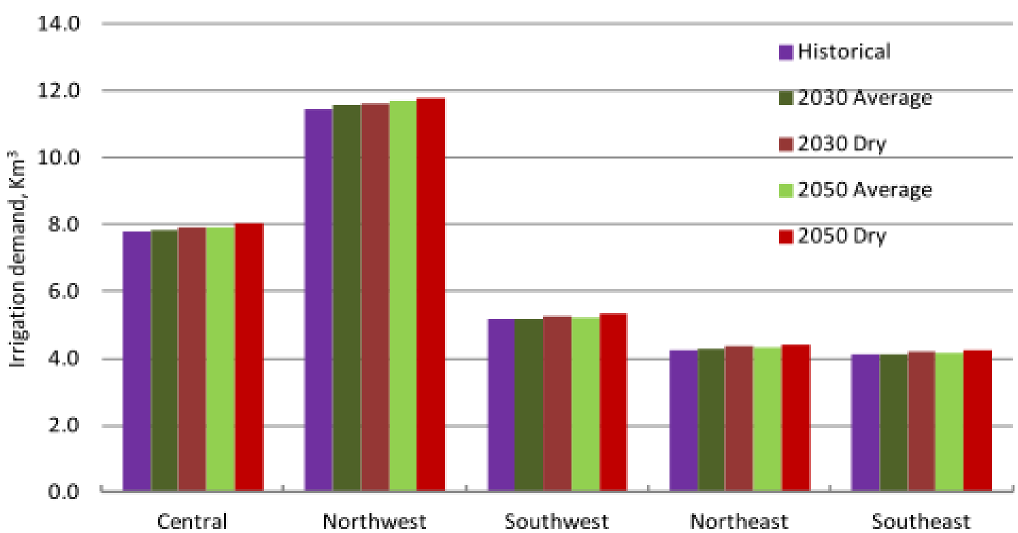

Figure 3.7: Expected impact of climate change on irrigation demand (Mainuddin, 2013)

3.3.3. Domestic and Industrial Water Demand

Based on CSIRO (2014) as most recent source of information, domestic and industrial use are on the rise, and are expected to grow by 100 and 440% respectively by 2050, as indicated in the table below. The current (2011) domestic water demand is estimated to be 2.7 bcm, which is expected to increase to 4.1 and 5.4 bcm respectively by 2030 and 2050 due to increase in population The corresponding figures for industry are 0.08, 0.18 and 0.35 bcm.

The major cities in the country have all prepared Master Plans including projections for future demand, as summarised in the table below (**Table 3.5**):

Table 3.5: Water demand projections for selected large cities in Bangladesh, in m^3/day

Name	2010	2015	2020	2025	2030
Dhaka	2108000	2144000	2616000	3130000	3901000
Khulna	129564	146890	169472	194676	228133
Chittagong[13]	712800	-	1243200	-	1896000
Rajshahi	104400	127132	157367	194528	245283
Rangpur	60269	77669	122476	170379	224987

Sources: Dhaka WASA Water Supply Master Plan; Master Plan for Water Supply & Sewerage Improvement for Khulna, Rajshahi and Rangpur (KEITI); Available Water Assessment and Salinity Intrusion Analysis for Karnaphuli, Sangu and Feni Rivers (IWM, 2008)

3.3.4. In-stream demands

The NWMP (2004) provides an estimate of in-stream demands, defined as the total of demands for salinity control, navigation and fisheries, dilution and environment. In calculating the water deficits per region (**Table 3.6**), the highest of the individual demands is adopted (as shown in the bottom line).

Table 3.6: In-stream demands in Mm^3 per season (Table 8.4, Annex C. NWMP, 2004)

Volume in Mm^3/season	NW	NC	NE	SW	SC	SE	EH	RE	Total
Salinity Control	0	0	0	7,335	18,338	1,027	660	18,338	45,699
Navigation and Fisheries	1,027	3,576	1,394	220	0	0	0	0	6,217
Dilution	0	917	183	367	0	0	367	0	1,834
Environment	2,179	167	1,635	210	15,101	414	523	16,956	37,183
Adopted	2,179	3,576	1,635	7,335	18,338	1,027	660	18,338	53,089

3.3.5. Deficits

Whereas overall water resources are sufficient at country level, concerns arise at regional level, particularly in the NW, NC and SE regions in the dry winter period, in which the ETo greatly exceeds rainfall, as illustrated below.

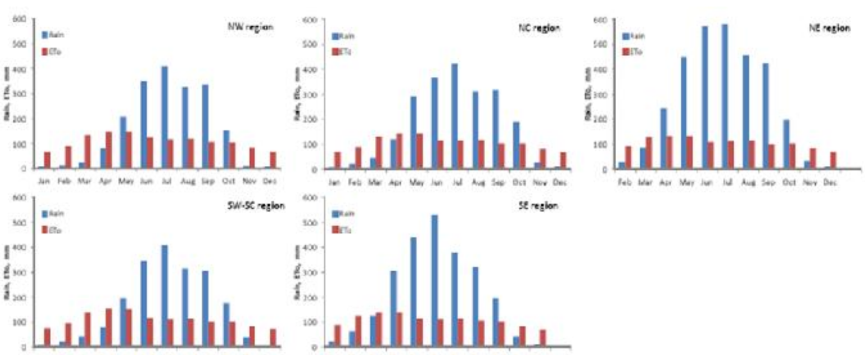

Figure 3.8: Monthly rainfall and ETo distribution (1985 -2009) in six regions (CSIRO, 2014)

[13] Water demand projections for Chittagong are based on the years 2011, 2021 and 2031

In the NWMP (Annex C Land and Water Resources), potential future shortfalls in the dry season are calculated for each region. Water needs are based on the total of water supply needs, in-stream demands (for whichever is the maximum of demands for salinity control, navigation, environment, fisheries or dilution of pollution), evaporative demands and net demands for irrigation. In the NWMP, demands are calculated using dependable rainfall and appropriate values of irrigation efficiency. From this total is deducted irrigation return flows from areas where irrigation efficiency is less than 100%.

The total is compared with the dependable surface water resources of the region to assess whether there is a surplus or a deficit. The comparison is made for the lowest three months, the month with the lowest fugitive resources and March – the month with the highest demand.

Based on this analysis (see Tables 9.1 to 9.8, Annex C, NWMP, 2004), only the SC, NC and EH regions are in deficit during the dry season (SW: 7616 Mm^3, NC: 2020 Mm^3, EH: 251 Mm^3). The North West Region is in overall surplus (even in the month of March, with the lowest available dependable flows) as groundwater is generally in good supply except in the western part of the High Barind, where recharge is limited, and in the Northern part of the Region, where groundwater is plentiful but the high incidence of boulders makes drilling difficult.

Balancing Water Demand and Availability

An accurate water balance is difficult to provide for the different HRs in Bangladesh. In the NWMP (2004), an overview is provided of the available water flows (static and fugitive) and water demand from key sectors. This includes 'traditional' sectors such as agriculture, domestic use and industry but also in-stream demands related to environmental and salinity control needs. However, as pointed out by MacKirby et al (2014), the NWMP does not provide a comprehensive water balance: it treats the ground- and surface water separately, and surface water is quantified in terms of dependable flows rather than the actual amount of water available and its variation from wet to dry years. Nevertheless, the NWMP was the first systematic attempt to quantify supply and demand in the country from the perspective of all water uses and is still the major source of information for water planners. A difficulty faced under the NWMP, which is still relevant to this day, is the complexity of surface water movement in the country. Bangladesh is characterised by complex hydrologic morphologic processes that are complex to model. Conditions in the monsoon are very different to those experienced during the low flow situation in the dry period. Great care is therefore needed in using hydrologic and hydrodynamic simulation models to represent both situations. Whilst there is much experience gained in modelling wet season flows in Bangladesh, application of the same approach to the dry season has not yet received sufficient attention (MWNP, 2004).

The study 'Bangladesh Integrated Water Resources Assessment supplementary report: approximate regional water balances' (Mac Kirby et al, 2014) aims to tackle some of these shortfalls: "The study brings together current information on rainfall, crop areas, evapotranspiration, groundwater levels and river flow to form approximate water balances for each region" (p vii). The regional water balances for three of the regions, lack the small river component however whilst the remaining two do not include net flows with the Ganges, Brahmaputra and Meghna. The study is therefore meant to assess the likely regional responses, "at least in direction, if not in absolute magnitude" (Mac Kirby et al, 2014) to changes in water availability under climate change and the substitution of surface water use for irrigation with groundwater. The authors explicitly indicate that the regional water balances are not meant for detailed water resource planning purposes.

WARPO is presently, as part of the update of the NWMP, carrying out an 'Assessment of State Water Resources', funded under the Water Management Improvement Project. As per the Inception Report;

published in April 2014, the project foresees in a comprehensive assessment of surface and groundwater resources, updating of the models used in the NWMP, including the WARPO Water Balance Model, the IWM models - Mike Basin, Mike-SHE and the River Network model - and the Single Cell Thana/Upazila (groundwater) Model developed for the NWMP. A main expected outcome of the assessment is a "calibrated and verified hydrologic and hydrodynamic model for the River & Estuary Region and other regional models for the dry and wet period". Other outputs include "the development of salinity and sediment transport models for selected rivers" and a "report on Trans-boundary river flows" (Inception Report, Assessment of State Water Resources, 2014). Once complete, this set of instruments, linked with the appropriate climate change models should be able to provide the much needed basis for detailed water resource planning, including scenario analysis and strategy evaluation, in the country.

3.4. Key Challenges: Floods and Droughts

3.4.1. Bangladesh most flood-prone country in the world

Normal flooding (*barsha*) affects about 30% of Bangladesh each year (FAO, NWMP: 22%), but land use and settlement are well adapted to it. The population has managed to adapt to these regular, seasonal floods and it is sometimes said that they are both 'a blessing' – through soil fertilization and the provision of breeding grounds for fish – 'and a curse' – through displacement of people, destruction of houses, the occurrence of water-related diseases and loss of life. The most extensive flooding generally occurs in the monsoon period when rainfall and river flooding coincide and the river levels do not allow for the drainage of rainfall floods from the adjacent areas. The most disastrous floods, in terms of lives and livelihoods lost, typically occur in the coastal areas when high tides coincide with the major cyclones (Brammer, 1996, NWMP, 2004, Baseline Study Coast, section 2.3)

About 1.32 million ha and 5.05 million ha of the total cropped area is severely and moderately flood prone respectively (FAO Aquastat, 2011), making Bangladesh the most flood prone country in the world. Abnormal flooding (*bonya*) can submerge more than 50% of the land area, damaging crops and property, disrupting economic activities and causing loss of life.

3.4.2. Types of flooding

Bangladesh is prone to four types of floods (Nabiul Islam, 1997 and 2006, and illustrated in Figure 3.9 and Figure 3.10:

1. Floods caused by high intensity rainfall during the monsoon result in 'normal' floods. They cause relatively little damage or even are beneficial as the silt and biomass that is deposited on the floodplain increases the fertility of the soil, and extend irrigation. These floods can however be aggravated by inadequate drainage, when water levels in the major rivers are high, or by blockage caused by roads and other infrastructure.
2. River floods are caused by spilling of water over the banks of major rivers due to heavy rains in the upstream catchment. This type of flood is often catastrophic, especially when the major rivers rise simultaneously.
3. Flash floods occur in the eastern and northern hilly regions. Flash floods have a relatively short duration, but generally have high velocities and a rapid increase in water levels. This makes them very destructive at local levels.
4. Cyclone induced tidal surges occur in the coastal areas consisting of large estuaries and low-lying lands. The surges mainly occur during the pre- and post-monsoon periods.

Flood Affected Area in Bnagladesh

Figure 3.9: Flood affected areas in Bangladesh

Source: Prime Minsters' Office Library *http://lib.pmo.gov.bd/maps/*

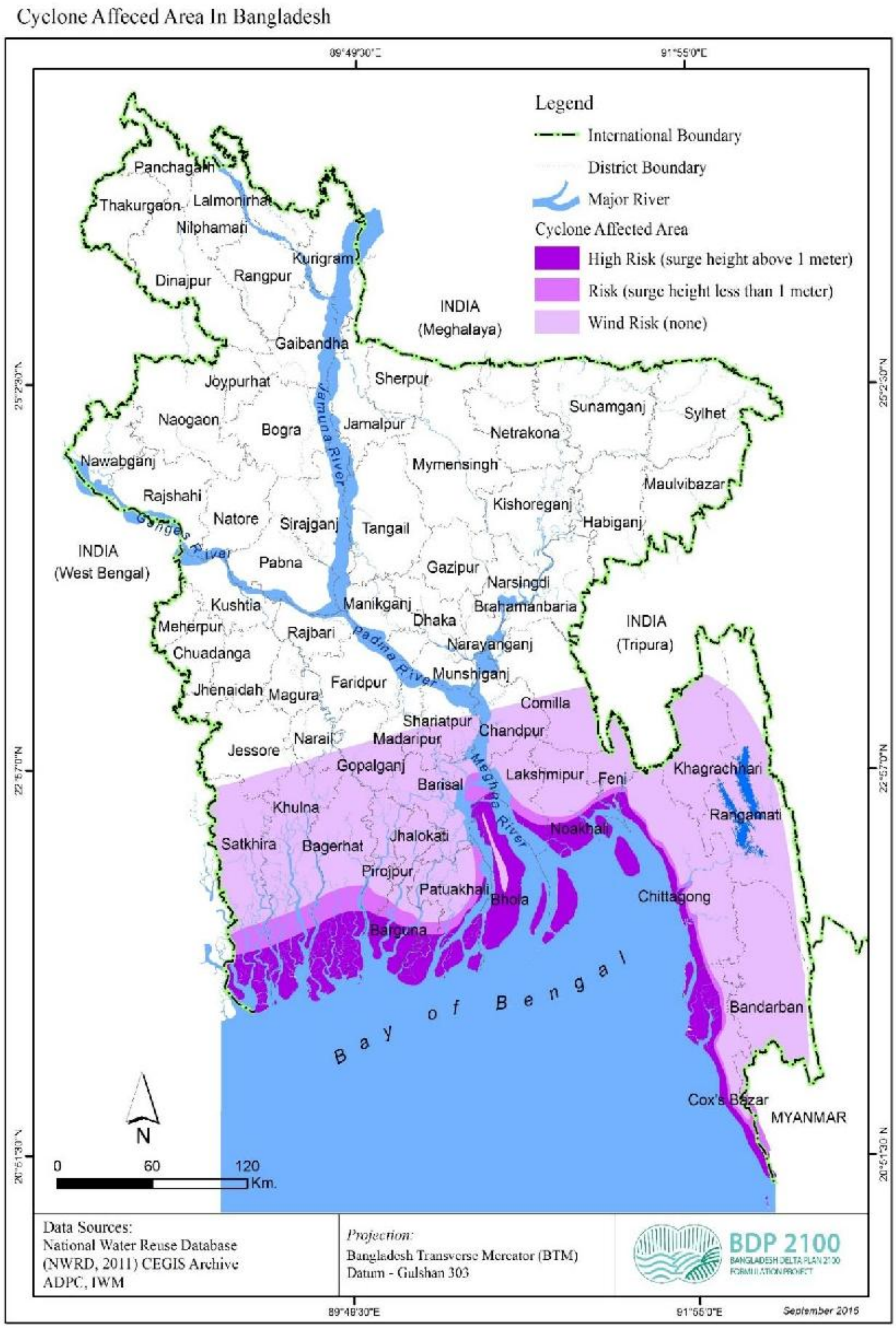

Figure 3.10: Cyclone affected areas in Bangladesh

Source: Prime Minsters' Office Library *http://lib.pmo.gov.bd/maps/*

The region-wise distribution of floods is as follows (**Table 3.7**): (Source: NWMP, 2004)

Table 3.7: Region-wise distrubtion of flood types (NWMP, 2004)

Region	Major Sources of flooding
Southwest	Tides and cyclonic rainfall
South Central	Tides, cyclonic rainfall and surges, and overspill of Lower Meghna
Northwest	Local intense rainfall, impeded drainage, breaches in the Teesta and Brahmaputra Right Embankments and breaches in internal polder embankments and drainage congestion preceded by high flows in the major rivers
North Central	Local intense rainfall, impeded drainage, spillage from the Brahmaputra and congested drainage on the Meghna
Northeast	Flash floods on transboundary rivers, local intense rainfall, impeded drainage and drainage congestion on the Meghna
Southeast	Flash floods on transboundary rivers, local intense rainfall, impeded drainage and drainage congestion on the major river
Eastern Hills	Flash floods and cyclonic rainfall
Rivers & Estuaries	High inflows through the Ganges and the Brahmaputra and surges

3.4.3. Flood frequency and extent

Seasonal floods inundate about one-fifth of the country each year on the average, whereas up to 60% of the country can be flooded during extreme events (NWMP, 2004). There can be big variations around this average, as illustrated in **Figure 3.11** below. The flood extent varies from almost 0% in 1994 to 68% of the total country in 1998. Peak floods occur on average every 10 years, with severe floods having occurred in 1954, 1955, 1971, 1974, 1987, 1988, 1998 and 2004.

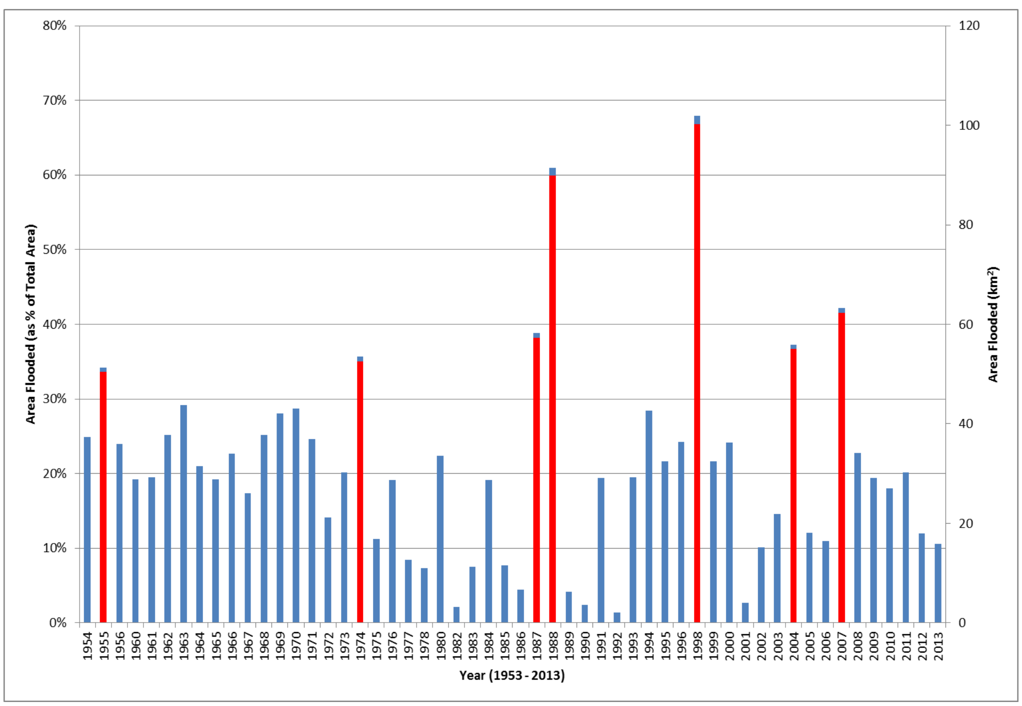

Figure 3.11: Annual Flooding (% and area wise)

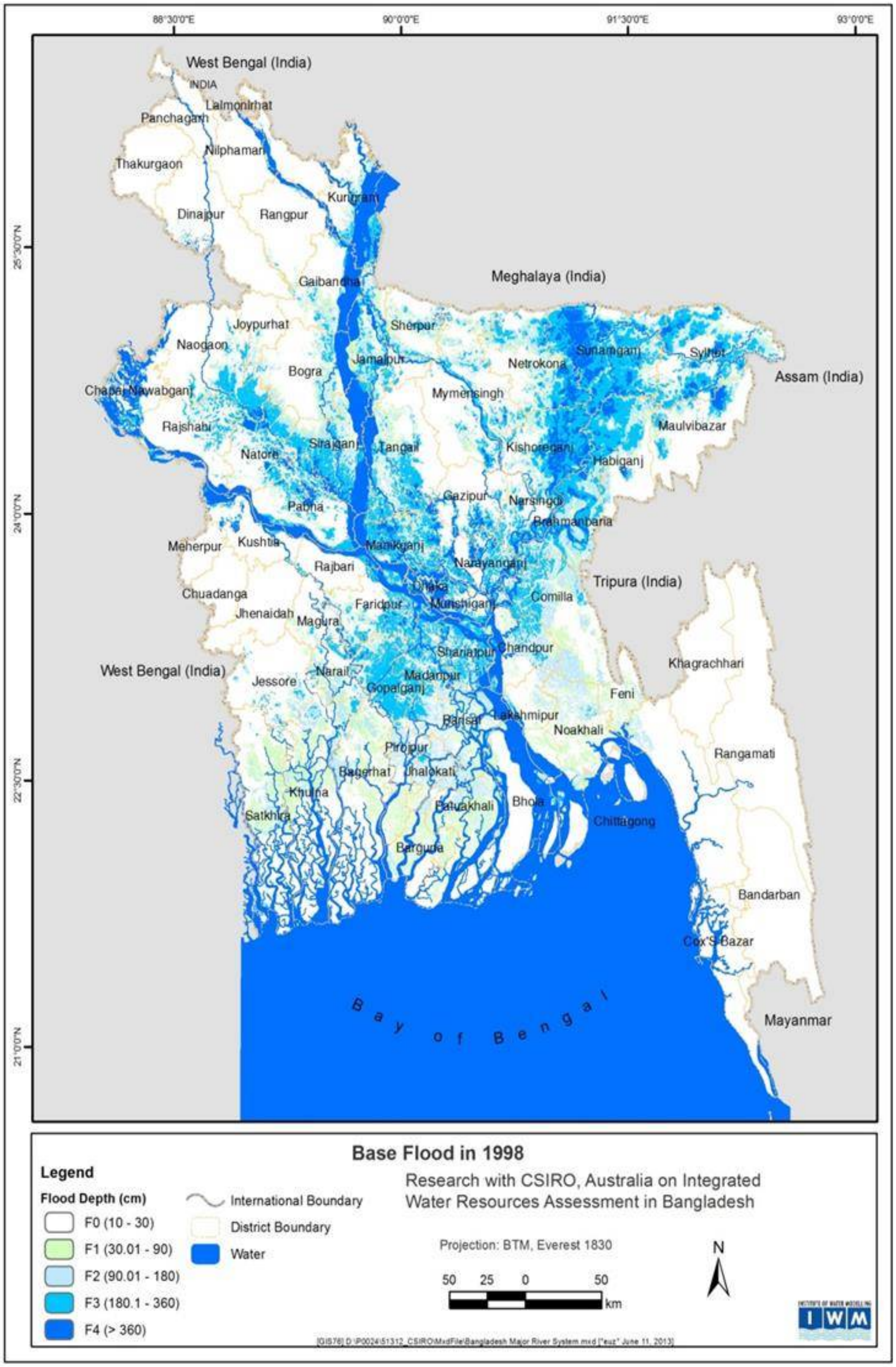

Figure 3.12: 1998 Flood Extent

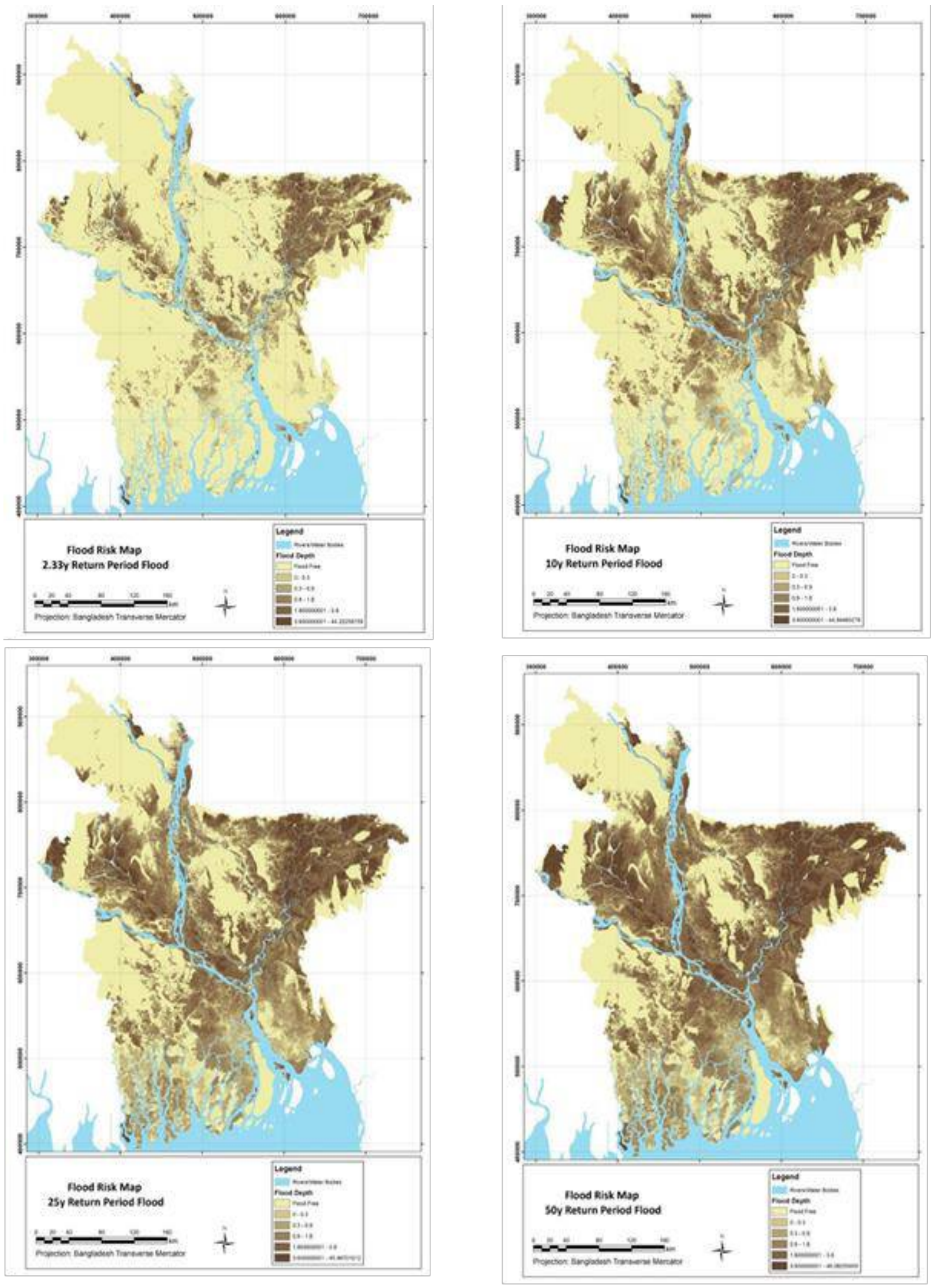

Figure 3.13: Flood Risk Map for 2.33, 10, 25 and 50 year return periods (IWM, 2014)

For this study, water depth maps were made (**Figure 3.13**) by IWM for floods with different return periods. The maps were developed using the 1D MIKE11 model in combination with GIS. The 10 year water depth map was made by interpolating the 10 year water levels for all locations. The digital elevation model of the country was subtracted from this interpolated water level map to obtain water depths. Water depth maps for different return periods were made in a similar manner. Although termed flood risk maps, these would also be termed flood hazard or water depth maps as they reflect the extent of flooding and not the damage, given the definition of Risk = Hazard x Effect. As can be seen from these maps, the increase in flood extent thus is rather small between a 10 year and a 25 year or 50 year flood extent.

Floods in the Chittagong region (as was indicated in the table above) are of a different nature than the Deltaic part of the country. Floodplains and towns (such as Thanchi and Lama bazar) are regularly flooded by flash floods from the Shangu and Matamuhri rivers. Panchhari is flooded by Chengi River. The affected areas usually remain waterlogged for a number of days after every flood and causes severe damage. The areas are also affected by cyclones and landslides are common during the monsoon. Key causes of landslides include soil erosion, deforestation and faulty agricultural practices. Landslides also cause increased siltation in the rivers (Quamrul Islam Chowdhury, Sustainable Development Networking Program).

3.4.4. Consequences of flooding

Benefits

The consequences of a flood are determined by the flood characteristics (water depth, flow velocities, duration), in combination with the vulnerability of the area (land use, building types). Although vulnerability has a negative connotation, floods have positive impacts as well. Positive effects that result from the normal monsoon floods include:

- Replenishment of lakes and ponds, so that the water can be used for irrigation and/or fish farming. Fish caught during the monsoon season is a key source of protein in the country;
- Production of monsoon rice varieties (Aus and Aman) for which the flood water is essential;
- Sediment supply to keep up with subsidence;
- The deposited biomass fertilizes the soil, for agriculture[14];
- Recharge of shallow aquifers, which are important for drinking water and irrigation;
- Flushing of salt from soils and surface water (increase fertility); and
- Navigation and transportation of goods.

Extreme floods usually have little benefits in the flooded area itself. Positive impacts can exist however, for farmers outside the flooded area as crop prices will increase and sales will increase. Companies that sell construction materials which are needed for recovery of the damage may also benefit from extreme floods. These latter benefits will however not compensate for the damage in the flooded area. The earlier mentioned benefits have not yet been adequately quantified and would need to be part of a thorough Socio-Economic and Environmental Cost Benefit Analysis as a precursor to large scale interventions in flood control.

Economic damage

Extreme floods can be devastating. Islam (2004) published damage to different sectors after the 1998 flood. About 50% of the flood damage was related to agriculture and nearly 40% to infrastructure. The reported values seem to reflect direct tangible damage. Nabiul Islam (2004) also made a comparison between the damage caused by the 1998 and the 2004 floods. The 1998 flood was of high magnitude and flooded 68% of the country. The flood also had a long duration. The flood flow remained above bankfull for nearly 1, 3 and 4 months in the Ganges, the Jamuna and the Padma, respectively. The flood extent of the 2004 flood was much less (about 38% of the country was flooded), but was much less anticipated (Nabiul Islam, 2004). The comparison leads to the conclusions that unexpected floods (such as flash floods) cause much more damage to infrastructure. The difference in damage

[14] The fertilising effect of sediments should not be overestimated. Silt is typically low in organic matter and has a detrimental effect on soil structure. Organic matter is brought in mostly though decaying of algae present in the flood water. See also: Brammer, 2014

caused to the agricultural sector is in line with the difference in flooded area as the flooding period was such that the affected production was completely lost (**Table 3.8**).

Table 3.8: 1998 flood damage to selected sector (Nabiul Islam, 2004)

Sector	**amount (crore Taka)**	**% of total damage**	**% of GDP 1998/1999**
Infrastructure			
- roads, bridge, railways & other infrastructure	1859	18.2	0.85
- residential sector	2090	20.4	0.95
sub-total infrastructure	3949	38.6	1.8
Industry	1227	12.0	0.56
Agriculture			
- crop sector	4377	42.8	2.0
- non-crop sector	675	6.6	0.31
sub-total agriculture	5052	49.4	2.31
Total	10228	100	4.7

The next table (**Table 3.9**) provides a comparison between the damages of the largest floods since independence.

Table 3.9: Damages resulting from major floods 1974 - 2007 (Islam and Mechler, BWDB, 2007)

Year	1974	1987	1988	1998	2004	2007
Affected area ('000 sq km)	53	57	90	100	56	62
Affected (million)	30	30	47	31	33	14
Fatalities	28,700	1,657	2,379	918	285	1,110
Houses damaged ('000s)	na	989	2,880	2,647	895	1,000
Roads damaged (km)	na	na	13,000	15,927	27,970	31,533
Crops damaged (million ha)	na	na	2.12	1.7	1.3	2.1
Asset losses (million US$)	936	1,167	1,424	2,128	1,860	1,100
GDP current (million US$)	12,459	23,969	26,034	44,092	55,900	68,400
Asset losses as % GDP	7.5	4.9	5.5	4.8	3.3	1.6
Estimated return period (years)	9	13	55	90	12	14

Damage on a national level

Although floods may locally lead to extensive damage, the damage at national and year-round level may differ. Crop losses during the monsoon season can be partly compensated for by an increased production of Boro rice in the same area. Nabiul Islam (2004) explains this effect by suggesting that farmers employ more effort in Boro rice production to compensate for the loss, and may also avail of more (ground)-water for irrigation. Farmers in unaffected areas may also anticipate higher prices and decide to invest their savings to obtain a higher output. Land flooding in the country is classified according to the maximum depth of flooding, with the 'F1' category (max^m depth of flooding 0.9 m) accounting for close to half of all the land susceptible to flooding. **Table 3.10** presents the distribution of land by depth of flooding.

Table 3.10: Distribution of land by depth of flooding (NWMP, 2004)

Land Type	Maximum depth of flooding	Seasonally flooded (average)	Permanently flooded	Approx. area (km^2)
Medium Highland 1(F0)	0.3m	16%	0%	12124
Medium Highland 2 (F1)	0.9m	44%	1%	34098
Medium Lowland (F2)	1.8m	23%	1%	18186
Lowland(F3)	3.0m	11%	3%	10608
Very Lowland(F4)	>3.0m	1%	1%	1515
Total		94%	6%	75772

The effects of flooding on the main Monsoon crop; Transplanted Aman Rice, can be severe, with up to 45% production loss in areas affected by severe flooding. During severe floods, the affected area may exceed 5.3 million ha or some 40% of the country and, in extreme events such as the 1998 flood, about 66 % of the country was inundated. Of the total cropped area, 1.32 million ha are severely flood-prone and 5.05 million ha are moderately flood-prone. (FAO Aquastat, 2011).

Casualties

Casualties are caused by the direct impact of the flood (drowning), but also occur in the aftermath of a flood due to polluted water sources and spreading of diseases. The 1998 flood is illustrative in this respect. About 30 million people were affected by the 1998 flood, and Reuters reported 1010 casualties in September 1998 *(http://reliefweb.int/report/bangladesh/bangladesh-floods-recede-death-toll-rises)*. Diarrhoea, caused by polluted water or rotten food, accounted for 208 of the 1010 deaths. Other deaths were caused by drowning, snakebites, collapsing houses and mudslides. Kuniiemail et al. (2002) conducted interviews among 517 people affected by the flood. Only 1.0% and 6.7% of the respondents treated water before drinking, by boiling and chlorination, respectively. 75% of the respondents, however, believed water collected from tubewells (93.2%) and rivers (6.0%) to be contaminated. A substantial number of these casualties can therefore be avoided by improved and robust drinking water and sanitation facilities and hygienic practices.

Relation between flood hazard and poverty

The impact and regular occurrence of floods is an explaining factor for the large difference in geographical concentration of poverty in Bangladesh. Floods also impact poor households' ability to escape from poverty by impacting on productive assets, productivity, houses, communication, health, water and sanitation. A positive relationship exists between flood risk and poverty as measured by household income, with people living under the poverty threshold facing a higher risk of flooding, as measured by their proximity to rivers and flood depth (Brouwer et al, 2007). Flood limits people to access public services such as health care, agriculture, treatment for livestock. Households living in flood-prone areas are caught in a vicious cycle with households that are affected most being forced to undertake distressed land selling and in doing so, risk being pushed into or deeper into poverty. These risks are particularly poignant for female headed poor households, which have even less opportunities for alternative incomes and assets to fall back on. Women's participation in water related disaster management is therefore the key.

3.5. Drought

In Bangladesh, drought is normally defined in terms of drought and severe drought, expressed as number of days without rainfall (10 and 20 days respectively). Although droughts are not always continuous in any area, they occur more frequently in the low rainfall zones of the country. Occurrences of drought as a major water deficiency related issue is most profound in the North-west region of Bangladesh (WARPO, 2001), which has the lowest average annual rainfall in the country. The average occurrence of drought in Bangladesh is once in 2.5 years (Hossain 1990, and Adnan 1993). Between 1960 and 1991, nineteen droughts occurred in Bangladesh (Mirza and Paul, 1992). The most notable droughts are described below (FAO, 2007):

1973 Drought responsible for the 1974 famine in northern Bangladesh, one of the most severe of the century

1975 Drought affected 47 per cent of the country and more than half of the total population.

1978-79 One of the most severe droughts in recent times with widespread damage to crops reducing rice production by about 2 million tonnes, directly affecting about 42 per cent of the cultivated land and 44 per cent of the population.

1981 Severe drought adversely affected crop production.

1982 Drought caused a loss of rice production of about 53,000 tonnes while in the same year, flood damaged about 36,000 tonnes.

1989 Drought dried up most of the rivers in Northwest Bangladesh with dust storms in several districts, including Naogaon, Nawabganj, Nilpahamari and Thakurgaon.

1994-1995 and 1995-1996 The most persistent drought in recent times, causing widespread crop damage, especially to rice and jute, the main crops of the North-west region and to bamboo clumps, an important cash crop in the region.

Types of drought

Different types of drought can be distinguished:

Meteorological drought occurs when the reduction in rainfall for a specified period (day, month, season or year) is below a specified amount – defined as s proportion of the long-term average.

Hydrological drought refers to deficiencies in surface and subsurface water supplies based on measurements of stream flow and lake, reservoir and groundwater levels. When precipitation is reduced or deficient during an extended period of time, this shortage eventually will be reflected in declining surface and subsurface water levels.

Agricultural drought occurs when the soil moisture available to the crop no longer meets the needs at a particular time. This type of drought is therefore highly crop (and soil) specific. Agricultural drought happens after meteorological drought but before hydrological drought.

Socio-economic drought occurs when physical water shortage starts to affect people and economic sectors.

Moreover, in Bangladesh, it is important to further distinguish **Seasonal drought**, even in the monsoon season, when overall rainfall is abundant and exceeds crop water requirements. Seasonal droughts are related to deficit soil moisture during certain periods within a season. Three types of droughts are recognized during the monsoon season: *early-season*, *mid-season*, and *terminal-season.* Early-season droughts are due to delayed onset or early breaks in monsoon rainfall. Mid-season droughts are caused by intermittent, short or extended dry spells. Terminal-season droughts are caused by early withdrawal of monsoon rainfall. In the Barind tracts of Bangladesh, terminal droughts are more frequent and coincide with the most important growth phases of the rice crop. **Figure 3.14** gives an impression of the regional and seasonal distribution of droughts in Bangladesh. Seasonal droughts in the Kharif season can occur throughout the country.

Consequences of drought

Past droughts have naturally affected about 53% of the population and 47% of the country (Mirza and Paul, 1992). The driest regions of the country is the North-west and South-west, which have experienced recurrent below-average rainfall. Perennial river flows are present in the major regional river systems, but many of the minor rivers lack sufficient environmental flows in the dry period. Since the main source for water use is groundwater, lowering of groundwater levels in aquifers due to rainfall deficit leads to water scarcity for households, industry and agriculture. The growing water demand is challenged in these areas by reduced water availability due to:

- Reduced river flow in the dry period because of channel bed siltation, upstream use and regulation, exacerbated by deforestation and climate change
- Salt water intrusion in the surface water system, because of reduced river flows and sea level rise (see also Baseline Study on Coast)
- Salinization of aquifers in coastal zones because of lowering of groundwater tables and sea level rise
- Declining groundwater tables due to over-extraction.

The droughts of 1994-95 in the north-western districts of Bangladesh led to a shortfall of rice production of 3,5 million tons (FAO, 2007). Since drought puts severe strain on the land potential, it acts as a catalyst of land degradation through reduced soil moisture and water retention, increased soil erosion, decline in soil organic matter content and degradation of natural vegetation. An analysis of the relative effects of flood and drought on rice production between 1969-70 and 1983-84 shows that drought is more devastating than floods to aggregate production. For a more detailed analysis of the consequences and classification of drought vulnerability, please see the Baseline Study on Disaster Management.

Dey (2011) pointed out (side) effects of droughts that are linked to livelihoods, among others: lower employment opportunities (less agricultural work has to be done), less food varieties (less crop types), and lower yields. Women headed households, particularly when they are not adequately recognised as farmers or do not have secure access to land, are particularly vulnerable to these type of drought risks. Specific attention should therefore be paid to ensuring access by Women to irrigation to secure family food security.

Although drought is most intensive in het North-western and South-western part of the country, other regions also cope with drought. In the North Central region for example, droughts are very much related to the activities in and around Dhaka. Available groundwater is not enough to meet evaporative demands and net irrigation requirements during the dry (Boro) season. Also urban water supply groundwater abstractions cannot be met in a sustainable matter and a shift to surface water abstractions is under consideration. (See for more details the Baseline Study on Water Supply). Regional inflows from the Old Brahmaputra and Dhaleswari, which have declined since the 1970’s due to morphological changes in the Brahmaputra (see Baseline Study on Rivers for a detailed analysis), are small compared with the flows needed for fresh water supply and navigation in the busy waterways around Dhaka, an example of socio-economic drought.

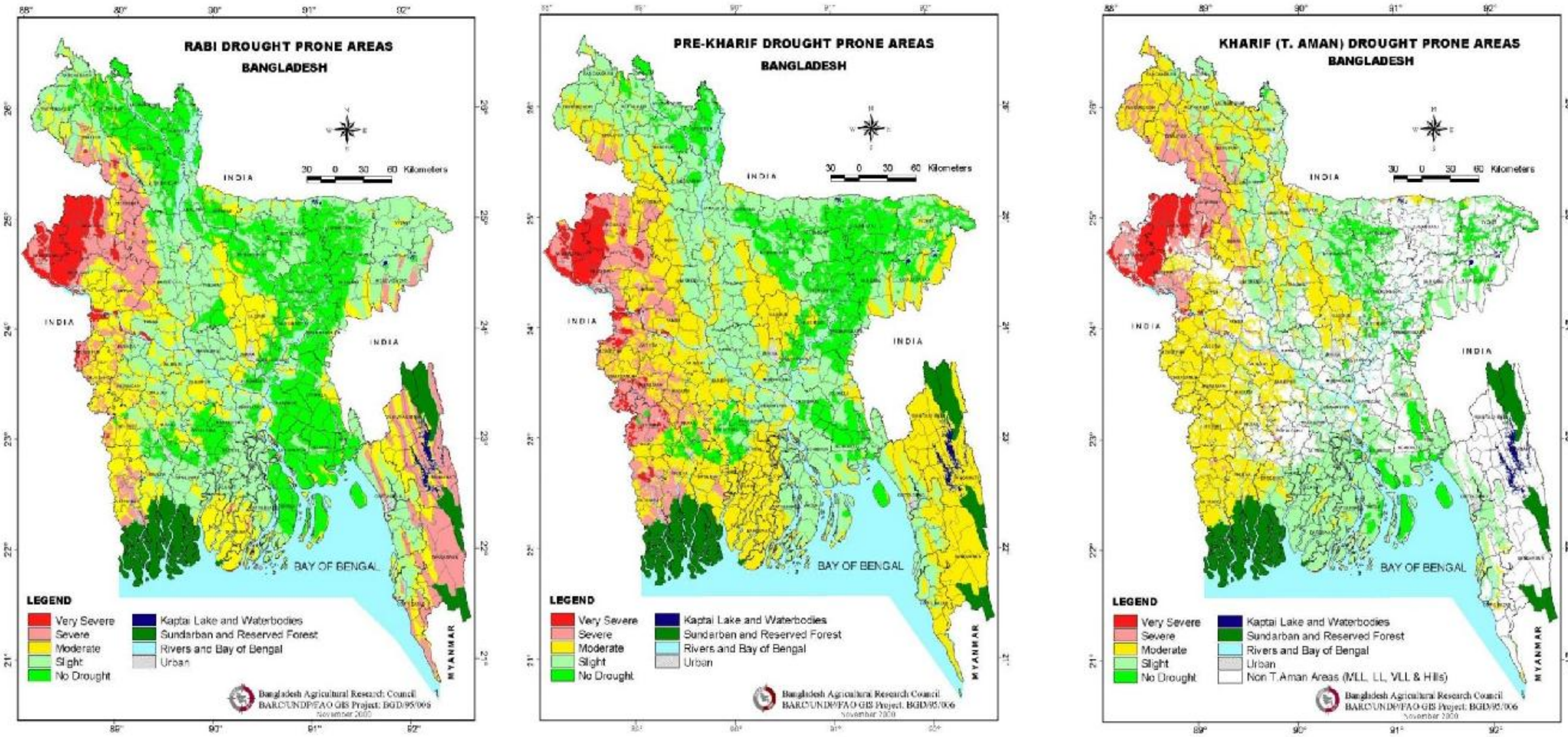

Figure 3.14: Regional distribution of (agricultural) drought (BARC, 2000)

3.6. International developments

Being highly dependent upon developments upstream, the diversion, use or storage of flows from the Trans-boundary Rivers is of major importance to Bangladesh. Impacts on dry and monsoon season flows, salinization, siltation of rivers and sediment deposition in the Meghna estuary are the most important factors. These, in turn have a direct impact on the ability of the (coastal) floodplains to keep up with sea level rise in the Meghna estuary.

Impact on dry season flow

International developments (i.e. the Indian River-Linking Project or IRLP) are expected to have a notable impact on the dry season flow. Through the project, water will be transferred and redistributed from the Brahmaputra and the Ganges basins through 30 link canals with an aim of inter connecting the major rivers of these two basins. The Ganges River has been found to be the most negatively impacted river among the major rivers followed by the Brahmaputra and to a lesser extent, the Meghna River. The most impacted regional rivers are: the Dudhkumar, Dharla, Teesta and Mahananda. Reaz A. Mullick at al (AIT, Bangkok, 2010) indicate that 'a reduction of the low flow in the Teesta in recent years results an alarming situation to the agriculture as well as to the in-stream users downstream to the barrage in Bangladesh part'. For the low flow season, the Mean Monthly Minimum Flow has decreased from 139 m^3/s in 1967 – 1990 to 110 m^3/s for 1991 – 2000, and to 50 m^3/s for 2001 – 2006. A closer analysis is required of the dry season flows of the Teesta is needed to understand these trends in relation to historical variations.

Changes in flows and sedimentation rates resulting from the development of the Farakka barrage may be illustrative of the type of impacts which may be expected as a result of further upstream infrastructure development (and especially increased diversion of flows for irrigation). According to M. Monirul Qader Mirza (1997), the diversion of dry season flows from the Ganges as a result of the construction of the Farakka dam, has caused considerable hydrological changes in the Ganges system in Bangladesh, notably a reduction in dry season flow and an increased siltation of the Gorai River (**Figure 3.15**). Hoelscher (2013, PRIO Report 1-2013) states that, referring to discharge (collected by BWDB) and precipitation data (collected by BMD) studied over the period from the 1940s' to the present for the Ganges river, '*These data appear to indicate that there has been a noticeable shift in dry season river flow volumes that coincided with commencement of operations of the Farakka Barrage. This downward trend appears independent of regular cyclical patterns of river flow, and independent of wet season flows.*' Hoelscher suggests that the (cyclical) decline of the dry season flows of the Padma may have been exacerbated by operation of the Farakka Barrage.

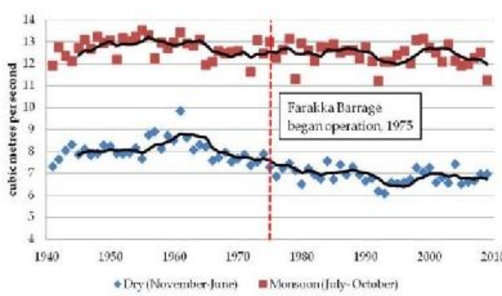

Figure 3.15: Average annual monsoon - dry season flows in the Padma River, Hardinge Bridge station, Kushtia (PRIO, 2013)

Based on the same data analysis (but then from different weather and discharge stations), Gain and Giupponi (2014) confirm these conclusions. It may be expected that further infrastructure development on the Ganges River will exacerbate the impacts outlined above. In addition to a further siltation of the rivers in the Ganges Dependent

Area (GDA), an increased salinization of the South-west Region will likely occur, further to the on-going trends. This will negatively impact the natural values of the Sundarban reserve and agriculture/fisheries in the GDA.

According to Hoelscher (2103), for the Brahmaputra and other main rivers, a trend such as described above for the Ganges, has not yet been observed. Hoelscher concludes that 'declines in dry season flows (based upon historical data) do not appear to be a concern for the Kushiara River, which does not show significant variation or declines from historical average flows.' This will alter if major infrastructure development takes place, resulting in changes in low and high flows and sediment transport through these rivers. Should e.g. the low flows for the Brahmaputra be affected in a similar manner as observed above for the Ganges, a comparable impact as for the GDA may therefore be expected for the coastal zones (i.e. the South-central hydrologic region) dependent on the Brahmaputra (and Meghna), entailing increased salinization and siltation of regional river systems.

Impact on Floods

The impact on floods would seem to be of a different order than droughts. The example of the development of the Farakka barrage may serve as example. Trends in peak flows in the Ganges are not statistically significant. However, decreased discharges during low flow periods may result in siltation of rivers and hence in higher water levels, even if no increase in discharge is observed. Bankfull discharge may occur at lower flows and induce more frequent flooding.

The Gorai river is a case at hand. Since the construction of the Farakka barrage, low flow discharge in the Gorai river decreased and the resulting siltation reduced the discharge capacity. Consequently, a larger part of the discharge now flows through the Ganges. The increase in water levels is shown in the stage- discharge relationship for the Gorai River. Monirul Qader Mirza (1997) shows that peak discharge in the Ganges has increased (**Figure 3.16**), but that no increase in water level was detected. He suggests that the river cross sections may have adjusted to the higher peak flows.

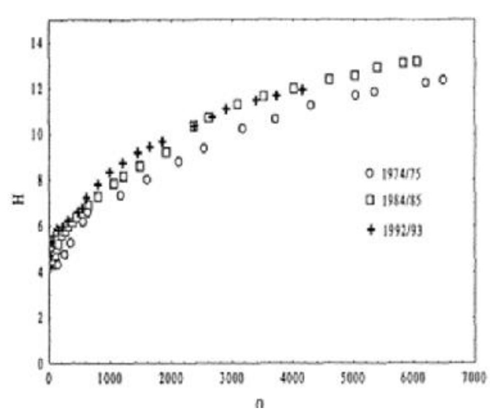

Figure 3.16: Stage-discharge relationships for the Gorai (Monirul Qader Mirza (1997)

3.7. Key Issues

Critical challenges in Bangladesh identified in this Baseline Report include:

i) Decline of wetlands and disconnection of these with the regional and main river system, especially in the Northern parts of the country, due to decline of dry-season flows, which are appropriated for consumptive use (irrigation, water supply and industries), and encroachment for agriculture and urban land use. This has a negative impact on water quality, the quality of capture fish habitats ad ecology and increases the pressure on ecologically sensitive areas.

ii) Water demand management. Future water demand depends to a large extent on the growth and characteristics of the agriculture sector, currently constituting some 90% of overall water demand. Industrial and domestic demands, although small if viewed at a national level, cause serious water resource constraints at local level, especially on groundwater. The SW region and selected parts of the NC and NW regions are in deficit regarding their surface water resources and this will increase if current agriculture and domestic/industrial growth patterns continue to develop. This trend is presently leading to unsustainable groundwater use in selected areas of the North-west and North-central hydrological regions (including Dhaka area).

iii) Decreased dry season flows and tidal flows in rivers in the South-west of the country, due to a decrease in dry-season flows of the Ganges river in combination with the obstruction of the drainage paths due to FCD construction. Waterlogging and increased salinity in the coastal area are key impacts.

iv) Deteriorating surface and groundwater quality caused by untreated effluent disposal by industries and domestic sources. Water quality worsens severely and some 32 rivers are considered at risk of severe environmental degradation, seriously affecting the services they provide to human and needs such as drinking and washing water and ecological functioning of rivers and wetlands.

v) Flood risks caused by riverine and coastal floods related to extreme rainfall, cyclones and storms. With economic growth and urbanisation, flood risks are expected to increase notably in the near future, also of critical infrastructure such as electricity supply and IT. A particular case is constituted by flash floods which do not allow for adequate response time.

vi) Waterlogging in urban and rural areas, caused by a number of factors, including unplanned and ineffective drainage infrastructure provision in local infrastructure, encroachment on wetlands in urban and rural areas and the hampering of tidal flows in the coastal area.

vii) Given the important role of women in providing drinking water and food security for their families and their own vulnerability to water hazards, specific attention is needed for position of women in securing adequate and safe drinking water, access to irrigation water and participation in water related disaster management;

viii) River bank erosion. The rivers in Bangladesh are morphologically very active. The annual rate of river bank erosion is about 6,000 ha per year. As a result, embankments can be undermined and farmers, especially those living at the Char lands, risk losing their land. The annual displacement is estimated at 50,000 people.

ix) River siltation: due to decreased low flow the rivers siltation is enhanced. This affects the desired water depths for navigation, discharge distribution between rivers as well as freshwater supply to dependant areas.

An overview of the key challenges for selected Hydrological Regions, developed as a result of three Stakeholder sessions with key experts[15], is provided in the Annex.

3.8. Main knowledge gaps and uncertainties

The main knowledge gaps and uncertainties with respect to water resources are outlined in this section – against the background of long term Delta Planning. The gaps were identified by the Study Team, based on expert consultation and review and analysis of previous water resource planning studies.

i) Environmental flow requirements: Environmental flows describe the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems. The present rule of thumb is that a minimum of 20% of the average flow constitutes the minimum environmental flow. Whereas this can be considered a starting point, a sounder scientific basis, related to the requirements of key aquatic species and other environmental requirements, is required.

[15] Documented in a separate Technical Note (unpublished) of the BDP. Experts consulted included Prof.

ii) To adequately assess the potential impacts of trans-boundary development on water resources, the following knowledge gaps have been identified:
   - Adequate assessment of the trans-boundary flow distribution – under different scenarios – and impact on:
     - Low and high flows in the Ganges, Brahmaputra, Teesta (and other minor) rivers
     - River morphology (sedimentation and erosion processes)
     - Groundwater recharge from cross-border aquifers and trans-boundary river systems
   - Climate change and its variability in the whole GBM Basin, affecting e.g. rainfall-runoff patterns and water balances for each Region and individual Catchments.
   - Changing pattern of water requirements due to upstream storage and consumption as a result of socio-economic developments in the different economic sectors, population growth, urbanisation and land use

iii) Quantification of the demand and supply (water balance), including international developments, climate change and in-country socio-economic development to determine the water budget for specific areas, impacts on surface and groundwater resources and carry out sensitivity analysis for different sectors, scenarios and strategies (including individual measures), Given the variation between the hydrological regions and expected impact of external drivers, these need to be detailed to the level of each region and hot spot.

iv) A better and precise estimation of groundwater resources in the country. For this purpose it is recommended to increase the understanding of morphology of the aquifer (extension and thickness), porosity of the aquifer, and groundwater levels. This information can be collected by compiling the already available studies undertaken for projects and more detailed studies regionally and further geophysical studies and monitoring campaigns where knowledge gaps exist on a spatial or temporal basis. More insight is needed in this process so that the impact of possible measures to enhance safety, such as embankments, and improved groundwater recharge can be assessed.

v) Water quality information for all rivers and aquifers at risk (at least the 32 identified before) and – for selected river reaches – modelling should be carried out to assess trends and impacts of proposed strategies and measures. The recently started project 'Water quality modelling of the Ganga River', in India (World Bank supported) may serve as an example to be followed in Bangladesh. The characteristics of deeper aquifers and salt-fresh water interactions in groundwater – particularly in the coastal region – also constitutes an important knowledge gap in view of future drinking water and irrigation demands.

vi) Impact – pressure relations: Impact-pressure relations are required to quantify flood and drought risks as well as to evaluate the effect of potential measures. For instance, validated flood damage and/or casualty functions are required to adequately assess flood risks and changes in flood risk caused by climate change, socio-economic developments or the implementation of measures. An integrated assessment is required of the impact of interventions on multiple indicators, at National and Local level.

vii) Computation of the actual flood and drought risks: damage information has been found for several floods and droughts, but information – and damage functions – on the actual risk in terms of expected annual damage in Taka per year, needs to be developed.

Challenges are natural- as well as man-made, including alternating floods and droughts, cyclones, expanding water needs of a growing population, large scale sedimentation and river bank erosion, rapid urbanisation, global warming and deforestation. An additional and growing challenge is the deterioration of surface and groundwater water quality and the maintenance of healthy aquatic ecosystems. Climate change and the lack of a sustainable financing of water resource infrastructure operation & maintenance further exacerbate these challenges.

There is a *clear need* to develop integrated water quality and quantity management, to maintain the capacity of the eco-system to deliver its services for the various economic sectors, maintain acceptable levels of flood risk and promote efficient and socially responsible water use. To face these challenges, integrated planning, knowledge development and innovation, sound delineation and cooperation between the public and private sectors and improved governance and institutional development are key points of attention.

4. Water Resource Planning and Organization

4.1. History of Water Resource Planning in Bangladesh

Although much development in the water resources sector is of a recent nature, floods and 'living with floods' has been part of life in Bangladesh for ages. Before the advent of the modern government administration, local management of Flood Control systems was a traditional feature. Examples include the construction of submersible embankments by *zamindars* in the North East Region and the low flood protection embankments in the coastal areas in the South West, dating back to the 1800s'. Local flood protection works on the Gumti date back even further (NWMP, 2004). An overview of the main historical developments in Flood Control in the 'modern period' is presented in **Table 4.1** (see also Baseline Study Coast, section 2.4).

Table 4.1: Overview of key historical events

(adapted from Md. Liakath Ali, 2002, additions by WR Study Team)

Period	Duration	Key events
Modern period	1947 – date	Krug Mission, 1956/7 and First Master Plan (IECO), 1964
		Start Coastal Embankment Project, 1968
		Land and Water Resources Sector Study (World Bank), 1972
		Creation of the BWDB and starting of small-scale FCD schemes, 1972 (through projects such as EIP, LRP, DDP, SRP, and others)
		Establishment Master Planning Organization, 1980 and WARPO in 1991
		National Water Plan I, 1986 and II, 1991
		Flood Action Plan, 1989
		Merger WARPO and FPCO, 1999
		National Water Policy, 1999
		Guidelines for Participatory Water Management, 2001
		National Water Management Plan, 2004 (completed in 2001)
		Coastal Zone Policy, 2005
		Haor Master Plan, 2013
		National Water Act, 2013
		Participatory Water Management Rules, 2014
		Integrated Water Resource Assessment (CSIRO), 2014
		Update National Water Management Plan (WARPO), on-going

4.1.1. The National Water Plans

In the modern history, water planning has featured prominently and has spurred much of the large scale infrastructure development. It started in the 1950s after the disastrous floods of 1954 and 1955. In 1956-7, a UN Mission, led by Mr. Krug, undertook a major review and recommended the construction of Flood Control systems on a large scale. Subsequently, in 1959, the East Pakistan Water and Power Development Authority (EPWAPDA) was created and assigned with responsibility for water resource (and power) development (NWMP, 2004, Md. Liakath Ali, 2002).

The first Master Plan

Along the same lines, major infrastructure development was proposed in the first Master Plan, drafted by IECO in 1964. In the Plan, 58 large-scale systems were proposed, covering 5.8 million ha, comprising embankments, pumping stations and canal irrigation. From the 1960s to the 1980s many of these systems were implemented, although in adapted form and without the provision for pumped drainage that was originally foreseen. One of the main principles underlying the master plan was that full flood control was the key to increasing *agricultural* production, by excluding river flood water from agricultural land and draining excess rainwater from the embanked areas by sluicing or pumping (EPWPDA, 1964 in Wester and Bron, 1988).

The Land and Water Study

Following the *Land and Water Study* of 1972, the development of small-scale irrigation, supported by low-cost medium sized FCD systems in shallow, flooded areas, received a major boost. The development of medium and later small sized FCD steadily increased, reaching 2.7 million ha in 1985 and approximately 3.5 million ha in the early nineties) to approximately 6 million ha today (NWMP, 2004).

The National Water Master Plan

In 1980, the Master Planning Organization (MPO) was set up, and the first national Water Master Plan was produced in 1986 and updated in 1991.

The Flood Action Plan

After the severe floods of 1987 and 1988[16], the Government of Bangladesh (GoB) requested the World Bank in 1989 to co-ordinate donor efforts for arriving at a comprehensive flood plan – resulting in the multi donor supported Flood Action Plan (FAP), which started in 1990. FAP lasted 5 years and consisted of 26 components, varying from a wide range of studies to pilot projects. Although FAP ended in 1995, a number of components continued with separate funding. Under the FAP, the basis was laid for future project planning and development, i.e. through the development of detailed Guidelines for Project Assessment (GPA), Environmental Impact Assessment (EIA) and Social Impact Assessment (SIA) and Guidelines for Participatory Water Management (GPWM) Practical experience with specific technical options was gained through pilot projects, particularly on river bank protection, compartmentalization, flood platforms, fish passes and dredging. Substantial further improvements were made to the country's database, which would evolve into the present day National Water Resource Data Base (NWRD) (NWMP, 2001). Experience gained in FAP resulted in first the formulation of the Bangladesh *Water and Flood Management Strategy* in 1995 (updated in 1997). The strategy became the working document for the water sector until the *National Water Policy (NWPo*) was made public in 1999 and subsequently a comprehensive *National Water Management Plan (NWMP*) was formulated (1999 to 2001).

The National Water Policy (NWPo)

The National Water Policy (NWPo) was the result of a series of comprehensive consultations and debates, involving both the public and private (NGO) sectors. The main objectives of the NWPo are:

a) To address issues related to the harnessing and development of all forms of surface water and ground water and management of these resources in an efficient and equitable manner.
b) To ensure the availability of water to all elements of the society including the poor and the underprivileged, and to take into account the particular needs of women and children.
c) To accelerate the development of sustainable public and private water delivery systems with appropriate legal and financial measures and incentives, including delineation of water rights and water pricing.

[16] In 1988 flood, over 60% of Bangladesh land area was inundated.

d) To bring institutional changes that will help decentralize the management of water resources and enhance the role of women in water management.
e) To develop a legal and regulatory environment that will help the process of decentralization, sound environmental management, and improve the investment climate for the private sector in water development and management.
f) To develop a state of knowledge and capability that will enable the country to design future water resources management plans by itself with economic efficiency, gender equity, social justice and environmental awareness to facilitate achievement of the water management objectives through broad public participation.

The new policy emphasizes the improved use of existing resources, public participation and increased emphasis on management and knowledge, in addition to water resource development.

The National Water Management Plan (NWMP, 2004)

The National Water Management Plan (NWMP), which was finalised in 2001 and formally approved in 2004, is the first Plan to be developed after the NWPo was issued and reflects the integrated water resource management approach laid down in the NWPo. The NWMP consists of a series of main documents, supporting annexes and a National and Regional Investment Portfolio. The preliminary results of the NWMP, derived principally from the WARPO database, expert consultations and the FAP studies, were initially discussed with a cross section of the population in two successive rounds of public consultations, in 24 locations in the first and 28 locations in the second round. Subsequently, the main issues were worked out into a set of working papers that were again discussed with the main stakeholders in both the public and private sectors[17]. The NWMP has 84 programs under eight clusters i) Institutional development, ii) Enabling environment, iii) Main rivers, iv) Towns and rural areas, v) Major cities, vii) Disaster management, viii) Agriculture and water management and viii) Environment and Aquatic resources (presentation Dr. Giasuddin Ahmed Choudhury, 2004)[18]. The water resource assessment carried out for the NWMP is currently being updated by WARPO, as part of the new National Water Resource Management Plan, with support from IWM, CEGIS and selected consultants.

WARPO, with support from IWM, CEGIS and international consultants, is presently carrying out an *update of the water resource assessment*. The assessment focuses on ground- and surface water resources, climate change impacts, and includes the updating of the water balance and groundwater models that were used to develop the NWMP (inception Report, Assessment of State Water Resources, IWM, 2014).

The ***Coastal Zone Policy (CZPo)***, based on an Integrated Coastal Zone Management (ICZM) approach, is discussed in detail in the Baseline Report on Coast and can be found at

http://www.warpo.gov.bd/iczmp.html.

The 6th Five-year Plan

The Sixth Five Year Plan (SFYP, 2011 to FY2015) of the Bangladesh Government ascribes significant importance to the water resources sector and the concept of Integrated Water Resource Management (IWRM) in support of economic, social and environmental sustainability. The plan cites different plans and policies relevant for the sector, i.e., Water Resources Planning Act (1992), the National Water Policy (NWPo, 1999), the National Water

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[17] The volumes have been published on the internet at *www.warpo.org*.

[18] See also the Annex – Factsheet on the NWMP

Management Plan (NWMP, 2004), the Guidelines for Participatory Water Management (GPWM, 2000), the Coastal Zone Policy (CZPo, 2005), the Coastal Development Strategy (CDS, 2006), the BWDB Act (2000) and the National Water Act which have created the enabling environment in the country. The programs and projects of water sector agencies such as BWDB and LGED are mentioned in as having played a key role in creating this favourable environment and providing concrete benefits to the country and its population.

SFYP Objectives and Targets for Water Resources

The SFYP advocates a balanced approach in setting the objectives of the water sector of the SFYP. Key priorities include i) river management (commonly known as river dredging); continued FCDI development; iii) trans boundary water sharing; iv) utilization of surface water as source of drinking water to combat arsenic contamination; and v) land reclamation. The use of Information Communication Technology (ICT) in water sector is also considered a priority as a step forward to convert the country into "Digital Bangladesh". The objectives for the water sector of the SFYP are:

1. People's participation in conformity with IWRM principals.
2. Enhancing conveyance capacity of water courses through river dredging.
3. Protection of river erosion.
4. Land reclamation.
5. Conjunctive use of surface and groundwater for sustainable irrigation.
6. Optimum use of available flows of the common rivers for multipurpose use.
7. Regional and International cooperation for basin-wide water resources development and management of trans-boundary rivers.
8. Flood Control/ Flood Management
9. Heights of coastal and flood embankments to be raised.
10. Food security by achieving food grains self-sufficiency through ensuring year-round sustainable irrigation.
11. Water conservation for irrigation and other uses.
12. Prevention of saline intrusion through augmenting the fresh water flow in the south west region including the Sundarbans (the world heritage).
13. Climate change adoption and mitigation.
14. Environmental protection.
15. Culture fisheries in the completed projects of BWDB.
16. Integrated coastal zone management.
17. Strengthening and capacity building of water resources institutions in the fields of
    - climate change issues
    - data management
    - river management
    - ICT arena
18. Studies and research on future water resources management.

Specific targets for the water sector in the SFYP are presented in **Table 4.2** below.

Table 4.2: SFYP targets for the Water Sector (6th Five Year Plan, GoB)

Expected outcome	**Unit**	**Quantity - Notes**
Employment Generation	Man days	12,5 million
Poverty Alleviation		Water sector projects are pro-poor

Expected outcome	Unit	Quantity - Notes
Protection of Environment		EIA is mandatory for all water sector projects
Social Security		Water sector projects are pro-poor
Food Security		Contributing about 10 million mt in food grains annually
Flood Control	ha	0,7 million
Human Resource Development		Train 3000 staff
Output		
Dredging of Rivers	Km	318
River Bank Protection (New)	Km	158
River Bank Protection (Rehabilitation)	Km	142
Embankment	Km	690
Re-sectioning of Embankment	Km	469
Coastal Embankment	Km	45
Re-sectioning of Embankment	Km	480
Coastal Cross-Dam	no	19
Excavation of Irrigation Canal	Km	1067
Re-excavation of Irrigation Canal	Km	1124
Excavation/Re-Excavation of Drainage Canal	Km	636
Irrigation/Hydraulic Structure	No	1117
Construction/Rehabilitation of Flood Control Structures	No	365
Reservoir	No	2
Rubber Dam	No	6
Barrage	No	2
Installation of Pump House and Rehabilitation	No	9
Formation of WMO's (in addition to Existing 7000 nos)	No	3000

SFYP Strategies and Budget for Water Management

The estimated budget for programs/projects included in the water resources sector of the SFYP is approximately Tk 235 billion. The plan emphasizes institutional, human resources, logistics and financial involvement for the successful implementation of the various programs and stresses the need for well thought out strategies and policies. The following strategies has suggested in the SFYP plan period:

- **River dredging:** Dredging would be carried out in a systematic and comprehensive way and that has to be done in combination with river bank protection for non-destructive, easy and smooth passage of flood flow of river system. Such a planned activity would help to protect the river banks from erosion, which is also a major vector of rural poverty. BWDB would take the lead role in this context.
- **Addressing dry season water scarcity:** In the wake of continued stress on surface water especially during dry season, top-most priority would be given on water-sharing of the common/trans-boundary Rivers with the neighbouring country/countries following the model of the Ganges Treaty (1996).
- **Basin-wide water resources development initiative:** Steps has to be taken immediately to enter into agreements with co-riparian countries for sharing water of international rivers, data exchange, resource planning and long-term management of water resources under normal and emergency conditions of flood,

drought and water pollution. While moving towards the attainment of basin-wide plans in the long run, it will also be necessary for Bangladesh to concentrate on the development of individual hydrological areas to meet short and intermediate term requirements.

- **The Ganges Barrage project with ancillary infrastructure:** The project would be undertaken with a view to meet several objectives, i.e. (i) to harness properly the benefits of the Ganges Water Treaty 1996 (ii) to save the Sundarbans and the south-west region of the country from salinity intrusion and (iii) to utilize the surface water in the wake of widespread arsenic contamination in groundwater, BWDB would address the issue within the shortest possible timeframe. This project is expected to benefit the South Western region and it is expected that 1.2 lakh ha lands would be under coverage of irrigation with fresh water, industrial water etc.
- **Participatory water management:** Such an approach would be followed in all water resources sector projects right from the identification up to monitoring and evaluation. The approach is mandatory for all public sector institutions.
- **O&M of completed projects:** The completed projects of water resources sector especially the projects related to flood control, drainage and irrigation would be properly operated and maintained with the participation of stakeholders so that the targeted benefits of the projects are ensured. Given the importance of these projects in terms of poverty alleviation of the rural population, BWDB would exert its effort to achieve this goal.
- **Achieving "Food-for-All":** BADC, BMDA and BWDB would continue to pursue command area development activities in surface water irrigation project and to explore expansion of irrigation.
- **Coastal zone management:** Coastal Zone is the zone of prosperity and at the same time is considered as vulnerable point within the country. The area would be treated as a special zone.
- **Public Private Partnership:** As water resources development interventions are costly initiatives, public-private partnership model has to be explored whenever possible.
- **Climate change:** The issue would be assessed on a realistic scale and then the effects of the issue on water resources sector would be addressed with reasonable care. BWDB, BHWDB, WARPO, RRI, IWM, JRC, BMDA, BADC and CEGIS would take joint effort in this field with WARPO taking the lead.
- **Land reclamation:** Bangladesh is facing land scarcity and in this context, necessary projects and steps would be taken for land reclamation. BWDB would implement projects for this purpose.

Continuous Monitoring and Updating of Water Resources

In view of the critical importance of water resources for the economy, the state of the water of the country in the perspective of time and socio-economic setting, the SFYP emphasizes the need for continuous updating and monitoring. WARPO with the help of all the stakeholders of the water resources sector especially with BWDB, BHWDB, JRC, IWM and CEGIS would update the National Water Resources Management Plan (NWMP). The organization will also achieve water resources data in the National Water Resources Database (NWRD). The National Water Management Plan (NWMP) would be updated through continuous monitoring of its implementation and the state of water resources in the country in perspective of climate change and social setting. WARPO would implement the update in consultation with all the relevant stakeholders including BWDB, LGED, DPHE, WASA, BADC, BHWDR, JRC, DoE and others. WARPO would also update the National Water Resources Database (NWRD) for future updating of NWMP.

Perspective Plan of Bangladesh (2010-2021)

The "Perspective Plan of Bangladesh (2010-2021): Making Vision 2021 a Reality" is a strategic articulation of the development vision, mission, and goals of the Government in achieving a prosperous Bangladesh grounded in political and economic freedoms a reality in 2021. The Perspective Plan, a road map for achieving the targets of Vision 2021, lays down a long-term strategy for different sectors. In water sector, it emphasizes the efficient, adaptive management considering the following aspects.

Integrated Water Resource Management: Although agriculture is the foremost user of the country's water resources, the Perspective Plan stresses the multifarious uses of water: industry, forestry, fishery, inland navigation, and domestic use including for drinking. The approach is, therefore, guided by the concept of integrated water resource management, aimed at optimizing water development and the way it is allocated to its various users.

Water Management for Irrigation: After analysing key challenges in terms of the abundance of water during the rainy season (June-October) and scarcity of water during the dry season (January-May, particularly March-April), the Perspective Plan points out that the country has little control over the annual run-off flowing through the country into the Bay of Bengal, so that cooperative regional water management becomes crucial for Bangladesh. A water sharing treaty exists only in respect of the Ganges and the Government is presently (2015) taking initiative to reach such agreements on Teesta and other rivers. Innovations in mechanical irrigation have led to a rapid expansion of irrigated agriculture in Bangladesh. The demand for water for irrigation is the greatest and the fastest growing, and, the Plan quotes the NWMP in anticipating on an increase in demand for irrigation by 25 % to about 20 BCM between 2000 and 2025 – and that under a best case scenario for irrigation efficiency. The goals for the irrigation sector include:

- Increase irrigation efficiency to 50% from the current 30%;
- Effectively address the overwhelming dependence on groundwater, focusing on increasing the use of surface water;
- Increase the irrigated area from 5 million ha in 2009 to 7 million ha by 2021 by using water saved from improvements in irrigation efficiency;
- Monitor the quality and quantity of groundwater through continuous surveys and investigation.

The Perspective Plan identifies two key challenges to achieving these goals:

Water scarcity: Less water will be available for irrigation in future, so water efficiency needs to be improved. Efforts will also be made to augment flows through trans-boundary Rivers by negotiating and undertaking joint actions with neighbouring countries – for example, with India and Nepal over the Ganges. For the long haul, the growing scarcity and competition for water for diverse uses may dramatically change the way water is valued and utilized, and the way it is mobilized and managed.

Climate change: Bangladesh agriculture is likely to be adversely affected as a result of the ongoing global climate change which is causing major changes in seasonal and spatial patterns of water availability, as well as a deterioration in water quality (through salinization, for example) and disturbance in hydrological processes. Appropriate adaptation measures, therefore, need to be developed through research and put to use widely over the Perspective Plan period.

Long-term Water Resource Management Strategies: Given the characteristics of Bangladesh's water sector, water demand, and the likely climate change impacts, the major Perspective Plan strategies include:

- Follow the IWRM framework for best allocation of water to various uses;

- Encourage research and development in designing appropriate adaptive activities to manage climate change impacts on and through the water sector;
- Encourage research on crop varieties that are water efficient and resistant to salinity;
- Focus on surface water irrigation and stabilize a reduced use of groundwater;
- Increase irrigation efficiency and reduce wastage and losses through better technology and better management;
- Encourage greater use of rainwater and its local storage for use in the dry season;
- Develop and implement efficient and effective measures to improve the knowledge gap of farmers on Farm Water Management technology;
- Examine large-scale O&M activities in embankments and polders to prevent salinity intrusion along the coast, and identify and implement the best option for the purpose; undertake desalinization activities;
- Rehabilitate coastal embankments to help adapt to climate change;
- Protect rivers from erosion of water courses and enhancement of land reclamation;
- Undertake planned and phased dredging and river training activities;
- Examine the government's water sector agencies and institutions and, if necessary, redesign, reorient and further equip them for more effective implementation of policies and strategies;
- Resume negotiations with India and other upper riparian states for equitable water sharing arrangements for all trans-boundary rivers, particularly major rivers.

Other Relevant Policies

The National Water Management Plan (NWMP), whilst based mostly on policy principles outlined in the NWPo, also takes into account other relevant policies formulated by Government. These include:

National Agricultural Policy (1999), aimed at, as was the case in former agricultural policies, is to maintain self-sufficiency in food, to achieve the ultimate objective of poverty alleviation[19]. Emphasis is placed on efficient irrigation and where this is possible from an environmental and social point of view (maintaining safe drinking water supplies), increase the development of groundwater irrigation. Specific attention is paid to promoting socially and environmentally friendly agriculture and maintaining a client-oriented agriculture system (National Agricultural Policy, 1999, NWMP, 2004).

National Fisheries Policy (1998), aimed at enhancing fisheries production, especially where capture fishing is a main activity, to boost export, prevent further drainage of water bodies and promote fisheries development in those bodies. Regarding the latter, the Fisheries Policy and the *National Wetlands and Wildlife Conservation Policy* coincide. The stated policy to preserve existing water bodies and enhance fish production, virtually limit any new FCDI development in the future in Bangladesh, unless FCDI systems are equipped with clear mitigating measures like fish passes and other fish-friendly structures.

The main gap identified in the Policy framework is a *National Policy on Land Use* or land use planning/zoning. The gap has been partly filled by the recently issued Government Ordinance (21st June 2001) concerning land us policy, prepared by the Ministry of land. Although many operational aspects remain to be defined, the principle of land zoning is taken as starting point for development, thus providing a basis for further policy development.

[19] From a poverty alleviation point of view, one can debate whether self-sufficiency in food production or rather sufficient purchasing power for the poor should be the aim.

Recently, the Government formulated the *National Water Act* (2013). The act stipulates that a National Water Resources Council will be formed, chaired by the Prime Minister and consisting of 11 ministries, representative from department in concerns and nominated national experts. Article 5 of the Act stipulates its functions, including the formulation of policies and guidelines for integrated development, sustainable use, equitable distribution and conservation of water resources. Particular mention is made, under Article 5, clauses (b) and (c) of its functions to 'give instructions in respect of making National Water Resources Plan, for ensuring integrated development of Water Resources', and 'to approve the National Water Resources Plan, and ensure implementation thereof'. An Executive Committee will work under the commission, the secretariat of which is formed by the Director General of WARPO.

4.2. Water Resources Management Institutions

4.2.1. Main organizations and functions

The main Government organizations involved in the water sector include:

- ***Ministry of Water Resources***, responsible for most aspects of the sector, including flood control, irrigation, drainage, water conservation, surface and groundwater use and river management. The *Bangladesh Water Development Board (BWDB)* and affiliated *Flood Forecasting and Warning Center (FFWC)* as well as the *Water Resources Planning Organisation (WARPO)*, responsible for water sector planning, drafting and updating the National Water Management Plan (NWMP), fall under the aegis of the Ministry. WARPO maintains the water resources database (NWRD) and is mandated to screen all proposed water related projects in the light of the NWMP, NWPo and relevant Guidelines and – as laid down in the new 2013 Water Act - acts as secretariat to the Executive Committee of National Water Resources Council (NWRC); the highest national body reporting to the Cabinet on all water issues. The 2013 Water Act lays the foundation for the future sustainable IWRM in the country. The BWDB was created in 1972, after independence as principal agency of the government for managing water resources of the country. It was given the responsibility of accomplishing the tasks of executing flood control, drainage and irrigation projects to increase productivity in agriculture and fisheries (BWDB was created under the Bangladesh Water and Power Development Boards Order 1972 -P.O. No. 59 of 1972) as a fully autonomous organization. As of 2000, the BWDB underwent a reform program and structural adjustment process, laid down in the 2000 BWDB Act. This act requires BWDB's functions be guided by the National Water Policy (NWPo, 1999) and National water Management Plan (NWMP, 2004). Policy making and overseeing the overall management of BWDB is vested in the Governing Council (GC) with thirteen Members headed by the Minister, Ministry of Water Resources. In addition, a number of research and coordinating institutes are affiliated with the Ministry: the *River Research Institute* (RRI), the *Bangladesh Haor Wetland Development Board* (BHWDB) and two trustee organizations: the *Center for Environmental and Geographical Information Services* (CEGIS) and *Institute of Water Modelling* (IWM).
- ***Ministry of Local Government, Rural Development and Cooperatives (MoLGRDC)***, organised into 2 divisions, the *Local Government Division (LGD)* and the Rural Development and Cooperatives Division. Under the LGD, the main implementing agency is the *Local Government Engineering Department (LGED)*, which supports the Local Government Institutions (LGI) at Village (Union Parishad) and Regional (Upazila or Thana) level. There are 4451 Unions and 464 Upazilas. Urban Drainage (sewerage and storm drainage), is the responsibility of the Major City Corporations and the Municipalities (Paurashava). The prime mandate of LGED is to plan, develop and maintain local level rural, urban and small scale water resources infrastructure throughout the country. LGED has been responsible for the implementation of the Small Scale Water Resources Development Sector Programme (SSWRDSP), now in its third phase. Over 500 FCD(I) schemes have

been implemented in the Western and Southern part the country. These schemes are, in line with the provisions laid down in the NWPo, below 1000has in size.

- ***Ministry of Agriculture (MoA)*****,** through its *Department of Agriculture Extension (DoAE)*, dealing with both extension and to a lesser extent social organisation of farmers and water users[20]. the *Bangladesh Agricultural Development Council (BADC)* with its particular mission to: 'Provide irrigation facilities to the farmer through minor irrigation activities' and 'Innovation of appropriate technologies for increasing irrigation efficiency' (see: http://www.badc.gov.bd/), the *Barind Multipurpose Development Authority (BMDA*), with a particular mandate to develop and manage groundwater resources for irrigation in the Barind tract, and the *Bangladesh Agricultural Research Council (BARC),* responsible for carrying out applied research on agricultural drought and on-farm water management . BARC also produces crop suitability and zoning maps for all major crops based on agro-edaphic factors, depth of inundation, flood hazards and landform (http://www.barc.gov.bd/) .
- ***Department of Public Health Engineering (DPHE)*** is the national lead agency for provision of drinking water supply and waste management in the country. DPHE is responsible exclusive for water supply and sanitation facilities throughout the country excluding Dhaka & Chittagong cities and Narayanganj and Kadamrasul Pourashavas where WASAs operate. DPHE provides advisory service to GoB in framing policy and action plans for WSS and provides guidance and support to the local government institutions (LGIs) in the development and O&M of the water & sanitation facilities.

- ***Ministry of Environment and Forests (MoEF)*****,** with its *Department of Environment (DoE)*, mandated to regulate and enforce environmental management, designate Ecologically Critical Areas (ECA), carry out water quality monitoring, pollution control and ensure the adequacy of Environmental Impact Assessments (EIA) and Environmental Management Plans (EMP).

- ***Ministry of Fisheries and Livestock (MoFL),*** through its Department of Fisheries, responsible for capture and culture fisheries.
- ***Ministry of Land***, mandated to develop and apply land zoning principles, and formally the custodian of all government owned (khas) land and water bodies.
- ***National Water Resources Council (NWRC)*** is the highest national body reporting to the Cabinet on all water issues. Its *Executive Committee (ECNWRC*) provides direct guidance and directives to the operational departments and organizations in the water sector.
- The ***Planning Commission*** is a national body responsible for screening and approving all development projects, drawing up the Five Year Plan and the Annual Development program (ADP).
- ***Regional, national and international NGOs*** have been involved in the water sector, both as partner as well as critic of FCD developments. NGOs have made a substantial contribution to the improved living standards in the country by assisting the rural population to cope with the disasters caused by the floods and cyclones. In the process of micro credit operation NGOs have organized groups, village centres or village organizations. Such groups are formed by marginal and poor male and female members and using micro credit a large number of group members have improved their livelihood and invested in small businesses, livestock and agricultural activities. In emergency cases these local groups are known to mobilize resources for repairs and maintenance. In a number of projects (SRP, EIP, SSWRSDP, IPSWAM), NGOs have been involved in FCD development as well, specifically in community mobilization and participatory planning.

Reference is made to the Baseline Study on Governance and Institutional Development for a more detailed discussion of water sector and general planning institutions in the country, as well as proposals to improve the planning process in the country.

[20] Agricultural research is carried out under the umbrella of the Bangladesh Agricultural Research Council (BARC). Ten research institutes pertain to BARC.

4.2.2. Water resource knowledge and information

The main knowledge institutions related to water resources are described here below. The list is not exhaustive and does e.g. not include many of the Universities active in the field.

Water Resources Planning Organization (WARPO)

WARPO is an apex organization under the Ministry of Water Resources, dealing with nationwide water resources planning. In 1983, the Government of Bangladesh created the Master Plan Organization (MPO) with a mandate to prepare National Water Plans. MPO became WARPO under act no. xii of 1992. The Flood Plan Coordination Organization (FPCO) was created in 1989 to coordinate Flood Action Plan (FAP) activities and was been merged with WARPO in January 1996. WARPO is a multi-disciplinary organization with a team of 44 professionals from a wide range of disciplines. The Water Resources Planning Act 1992 and the National Water Policy of the Government of Bangladesh mandated and assigned various important responsibilities. These are grouped into two categories, namely: routine core function and periodic functions.

River Research Institute (RRI)

The RRI is a national organisation working as a statutory public organisation under the Ministry of Water Resources. RRI carries out multidisciplinary and problem oriented tests in the field of river, coastal and structural hydraulics, irrigation hydraulics, soil mechanics, material testing & quality control, sediment technology, hydro-chemistry, geo-chemistry and instrumentation. Results of test and research play a vital role in providing information and recommendations on different water resources development plans an interventions. The RRI avails of physical modelling facilities, as well as, to a certain (recent) degree, mathematical modelling facilities.

Institute for Water Modelling (IWM)

IWM provides the services in the field of Water Modelling, Computational Hydraulics & Allied Sciences for Integrated Water Resources Management. IWM has developed high level analytical capabilities in the state-of-the-art mathematical water modelling to support its water resources management. The applications of IWM modelling tools cover a wide range of water related areas such as: flood control and flood forecasting, water supply and urban water management, irrigation and drainage, river morphology, salinity and sediment transport, coastal hydraulics, port, coast and estuary management, environmental impact assessment, climate change modelling, bridge hydraulics and related infrastructure development. IWM operates under the aegis of the Ministry of Water Resources.

Centre for Environment and Geographical Information Systems (CEGIS)

CEGIS is an independent organization and performs integrated environmental analysis using technologies like GIS, Remote Sensing, Advanced Information Technologies, Applied models and databases. It provides solutions to issues and problems in a wide range of sectors, such as water, land, agriculture, meteorology, forestry, fisheries, morphology, ecology, environment, climate change, archaeology, socio-economy, power, transportation and disasters. CEGIS operates under the aegis of the Ministry of Water Resources and operates and maintains the National Water Resource Data Base for WARPO.

Bangladesh University of Engineering and Technology (BUET) – Department of Water Resource Engineering (DWRE) and Institute of Water and Flood Management (IWFM)

The Department of Water Resource Engineering (DWRE) was established at BUET to support the nation's water resource challenges. DWRE offers Degree (Bachelors and Masters) and PhD Programs in Water Resources Engineering and Research Programs for the sustainable management and development of the complex water resources system. Research areas include: River Response, Training Works and Erosion Protection, Hydraulics and Hydraulic Structures, Coastal Engineering and Coastal Zone Management, Hydrology and IWRM, Climate Change, Groundwater Engineering, Irrigation and Drainage Engineering, Numerical Modeling, GIS and Remote Sensing (http://www.buet.ac.bd/wre/). In addition, DWRE offers Advisory and Consultancy Services in these fields to Government and Industry.

The occurrence of floods, droughts, cyclones, river erosion, siltation, and water scarcity in the dry season have made water management a challenging task. The gradual degradation of the environment due to human interventions is adding further complexities to water management. To address these issues, the Institute of Flood Control and Drainage Research was established in 1974 and later renamed as the Institute of Water and Flood Management (IWFM) within BUET in 2002. The Institute pursues research and capacity development in the field of water and flood management that is vital for economic development and social prosperity of the country. The Institute also provides advisory and consultancy services to government and non-government organizations.

Bangladesh Institute of Development Studies (BIDS)

A key knowledge institution in terms of development policy research and development is the Bangladesh Institute for Development Studies (BIDS), established in 1974. BIDS is an autonomous public multi-disciplinary organization which conducts policy oriented research on development issues. It undertakes particularly relevant research in the field of flood damage.

4.2.3. Participatory Water Management

The concept of Water User Groups becoming responsible for water management O&M and organized into a multi-tier organization was been adopted as policy by the Government of Bangladesh with the publishing of the Guidelines for Participatory Water Management (GPWM) in 1999. A three-tier Water Management Organisation (WMO) is foreseen consisting of the Water Management Group (WMG), Water Management Association (WMA) and Water Management Federation (WMF). The principles that govern the establishment of these organizations are laid down in the NWPo.

The Guidelines foresee that in small schemes (below 1000 ha), a number of WMGs and 1 WMA would be responsible for management. In schemes above 5000 ha, a WMF as Apex body would be established. For schemes between 1000 and 5000 ha, a WMF may be established according to need. The GPWM foresee that the WMA would be registered as Co-operative in accordance with the Co-operative Societies Ordinance (1984) and its subsequent amendment; the Co-operative Societies Rules (1987) and guided by specific By-laws. The concept of Water Management Co-operative Associations (WMCA) has been in place since 1987 when LGED pioneered this form of organization. In practice, over the last 10-15 years, a number of models have been pioneered, with and without Cooperative registration. The lead has been taken by projects such as PSSWRSDP, IPSWAM and CDSP and WMIP. A key issue remains the lack of sustainable financing of O&M, at scheme and catchment level.

4.3. Key Issues

i) Closing the gap between Planning and Implementation and ensuring the coordinated and integrated development of water resources at national, regional and local level. This includes developing water budgets at Regional and Catchment level and accompanying Water Allocation Plans that ensure adequate supply and water quality for the priorities in the area.
ii) Coordinated and well planned river management taking into account river morphology, the different river functions and the interaction between the main rivers and regional river/floodplain systems.
iii) Securing O&M financing at local, regional and national level, including the development of public-private management models, for irrigation in particular.
iv) Application of the IWRM concept at catchment and sub-catchment level, based on reliable and up to date data and models, taking into consideration all IWRM aspects and ensuring a good access to information by all stakeholders in the area. This includes the development of a hands-on and well equipped water resource management organisation.
v) Sustainable WMO model development, incorporate the different interests of water users and stakeholders at local and regional level based and incorporate these interests in day-to-day and long term water resource management.
vi) Implementation, monitoring and enforcement of regulations in both water quantity (surface and groundwater) and water quality.

4.4. Main knowledge gaps and uncertainties

The main knowledge gaps and uncertainties with respect to water resources planning and organisation are outlined in this section. The gaps were identified by the Study Team, based on expert consultation, review and analysis of previous water resource planning and organisation studies and evaluation reports. Reference is made to the Baseline Study on Governance and Institutional Development for a more detailed assessment.

i) Developing a reliable (GIS) database of the actual state of infrastructure and physical assets, water resources, and financing needs for sustainable infrastructure management.
ii) Defining the set-up of a suitable institutional water management model for IWRM at regional and catchment level, able to deal with the inherent future uncertainties with respect to water security and socio-economic development.

5. Outlook and Future Challenges

5.1. Scenarios and Drivers of Change

Both future climate and socio-economic changes are inherently uncertain in today's world and can therefore not be well predicted. Rather, science can provide a range of future projections based upon which water resource planners can develop and evaluate strategies that are able to deal with multiple possible futures (= scenarios). Scenarios also assists in identifying which decisions and investments can and should be made in the short term and which options should be reserved for later. In the project, a dedicated 'scenario group' is developing a set of scenarios and identifying key drivers of change for use within the BDP, based upon which the impact on water resources can be assessed. In addition, the scenarios are needed to evaluate the robustness of potential measures and strategies. In this chapter, a first assessment is made of the potential impacts on water resources. This will be refined at a later phase of the project. Key drivers of change include population increase, industrialisation and urbanisation, changing consumption patterns and international (regional) developments. The main impacts defined here included those impacts due to worsening water availability and quality, floods and displacement in relation to river erosion.

5.2. Potential Impacts

5.2.1. Water availability

According to climate change scenarios, extreme temperatures and precipitation are expected to increase (Kumar et al, 2006). However, natural variability is expected to dominate the climate change signal, at least up to 2050 (Moors et al., 2011; Jeuland et al., 2013; CSIRO, 2014). The Bangladesh Integrated Water Resource Assessment (CSIRO, 2014), concludes that: "with climate change reducing GDP by -0.327% by 2050, population growth dynamics, productivity growth and trade policy may have more profound effects on the economy than projected climate change." According to previous projections (NWMP) and recent analysis carried out by CSIRO, socio-economic developments such as population increase and increased non-agricultural water demand, but also increased urbanization will have a far greater impact on changes in water demand and availability than climate change.

Drought or dry season low flows are strongly differentiated in area and time over the country; in the low rainfall zones and/or high density populated area, such as the NC zone which include the Dhaka Metropolitan Area, vulnerability to droughts will further increase. This would need to be a core topic for further analysis in the next step of Bangladesh Delta Plan (Scenario and Strategy Analysis). In addition, with a continuation of the current level of economic growth, it is expected that water users will demand and value a higher level of water management, both in terms of reliability, quantity and quality. This in turn will require water managers to increase the effectiveness and ability to respond to changing demands.

In addition to the agriculture, industry and domestic sectors, water availability - and habitat connectivity[21] - is impacting the wetlands in particular. As an example, out of Bangladesh's 260 freshwater fish species (Rahman, 2005), more than 40% species are now threatened with extinction (IUCN Bangladesh, 2000). Based on Landsat image interpretation during three dry seasons of 1989, 2000 and 2010, it was found that the total wetland area in the North-west region (the region with the largest number of beels in the country) declined from 1208,72 to 903,54 and 867,18 km2 respectively. This indicates a decrease of 25,25% wetland areas from 1989 to 2000 and 4,02% decrease in wetland areas from 2000 to 2010 (Shopan et al, 2013). Analysis by Mahmud et al. (2011, in Shopan et al, 2013) for Dhaka Metropolitan Area between 1978 and 2009 revealed that area of wetland and Rivers & Khals in Dhaka city decreased significantly over the last 30 years by 76, 67% and 18,72% respectively.

International developments (i.e. the Indian River-Linking Project - IRLP) are expected to have a notable impact on the dry season flow. Through the project, water will be transferred and redistribute from the Brahmaputra and the Ganges basins through 30 link canals with an aim of inter connecting the major rivers of these two basins. The Ganges River has been found to be the most negatively impacted river among the major rivers followed by the Jamuna and the Meghna Rivers, while the most impacted regional rivers include Dudhkumar, Teesta and Mahananda Rivers. The six adjacent hydrological regions (North West, North Central, North East, River and Estuary, South West and South Central) of the country would be impacted at various magnitudes. The drought impact as described in the regions above could intensify as a result of these international developments.

5.2.2. Water quality

Industrialisation, which includes the industrialisation of the agriculture sector, urbanisation and salinization, are expected to lead to further deterioration of surface water quality in the country. There are at least three types of direct negative impacts of water pollution: i) increasing health problems of the rural and urban population; ii) loss of agricultural and industrial productivity due to pollution and salt water intrusion; and iii) environmental degradation, leading to a degradation of the environmental services offered.

IWM estimate in its study on water quality in Dhaka City area (2007), showed that Health care cost of pollution represents 21.5% of annual income in Hazaribag area. According to the World Bank (2010), the loss of amenities associated with contaminated surface water amounts to about 0.5% of the region's GDP. In polluted areas of the Dhaka Statistical Metropolitan Area (DSMA), 45% of households report persistent losses in the production of rice and more than 20% are experiencing production losses in vegetable crops. Less than 15% of households in highly polluted areas allow livestock to drink river water, compared with more than half in the past. It is estimated that agricultural and fisheries production in the DSMA may be reduced by about one third as a result of poor water quality (Bangladesh Environmental Management Project, BEMP, 2005). Estimated annual costs amount to some US$ 400 million linked to poor surface water quality, including lost agricultural and fisheries production (17%), costs to industry (22%), lost amenities (21%), and health costs (40%).

Key issues in groundwater quality include arsenic in groundwater and salinization, whilst pollution from industrial and domestic sources is not yet well known, but constitute a clear risk. A recent study (Flanagan et al. 2012) reports that over the next 20 years Arsenic-related mortality in Bangladesh (1 of every 18 deaths) could lead to a

[21]See Chapter 2 for a discussion of wetland connectivity in relation to FCDI infrastructure development

loss of US$ 12.5 billion assuming a steady economic growth and an unchanged population exposure to arsenic contamination. Salinization of groundwater, which is some areas is prevalent at 100 km land inwards, is another key risk.

5.2.3. Floods

Uncertainty in *climate change* projections makes any computed impacts on peak flows uncertain as well. Nevertheless, many studies indicate that the total annual flow as well as the peak flow of the Ganges and Brahmaputra will increase (CSIRO, 2014). Increased surface water inflows and greater monsoonal precipitation will increase flooding. Along the coastal area flooding is also likely to occur more frequently due to sea level rise and increased storm surges. To obtain an indication of possible changes in climate on peak flows of the major rivers in Bangladesh, IWM (2014) assessed the modelled impact on rainfall and temperature for several locations in the Ganges, Brahmaputra and Meghna basins. The changes in climate were averaged for all global circulation models. The average change of the remaining models was used to derive input data for Mike-Basin models of the three rivers. The results (also published in CSIRO, 2014) indicate increased river discharge, especially during peak flows. The peak flow of the Ganges at Hardinge Bridge during the 1998 flood was about 72000 m^3/s. This could increase to more than 90000 m^3/s in 2050. This is a 25% increase. In the Brahmaputra River, climate change could increase peak flows by about 15% (from 103000 m^3/s to 116000 m^3/s).

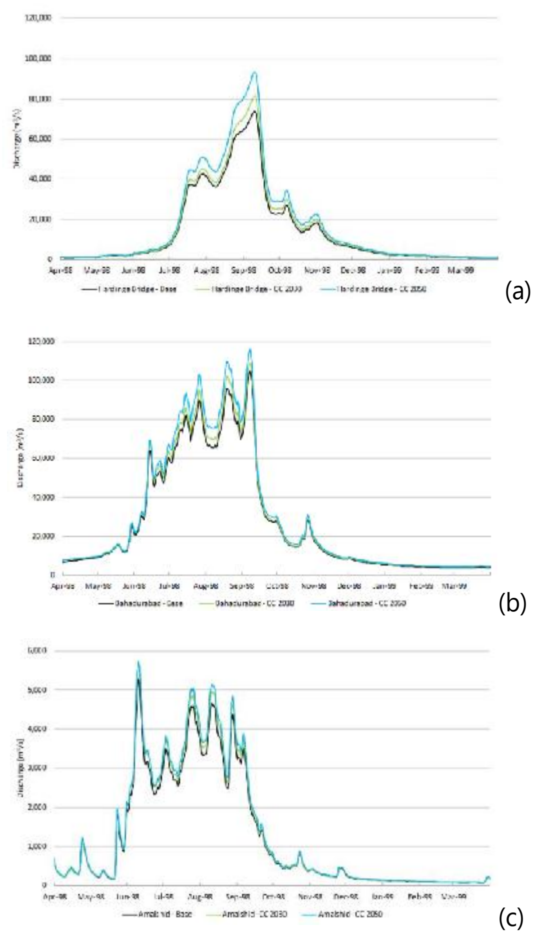

Figure 5.1: Expected increase in river discharge for the three major rivers in Bangladesh (a) Ganges, (b) Brahmaputra, (c) Meghna depicted on the 1998 flood (IWM 2014 in CSIRO 2014)

Nabiul Islam (2014) anticipates the Bangladesh economy to grow with more than 6% per year. The projected growth until 2050 suggests an increase in GDP by a factor 15. Much of this growth will be brought about by industrialisation and development of the services sector. Although not all of the economic growth results in increased economic value of the flooded land, this will nevertheless result in an enormous increase of the annual flood risk[22]. According to the NWMP (2004, volume 2), population growth has slowed to less than 2% per year. In absolute terms this implies that the population is expected to increase from about 129 million in 2000 to 181 million in 2025 and 224 million in 2050. This is a 70% increase over a period of 50 years. If no measures are being taken, the number of people affected by floods will also increase by about 70%. The same may also apply to the expected number of casualties.

5.2.4. River erosion

A further expected future impact is river erosion, affecting on average, some 6000 ha of river banks erosion in the country on an annual basis, leading to the displacement of about 50000 people. The net erosion and accretion for the period 1973–2013 is estimated to be 103995 ha. Impacts of river erosion are discussed in more detail in the Baseline Report on Geo-Morphology and River Management.

5.3. Potential for Future Development and Promising Strategies

In identifying and structuring potential strategies, the results are drawn of a number of *key expert consultation sessions* held as part of the Baseline Study and the *Report on Bangladesh National Consultation on the Sustainable Development Goal and Target for Water in the Post-2015 Development Agenda*, a consultation carried out with the Bangladesh Water Partnership (BWP) to feed into the world-wide GWP consultation process. Moreover, the results will be related to the concept of Water Security as adopted by the Asian Development Bank (ADB) in its 2013 Asian Water Development Outlook (AWDO, 2013) but also the Global Water Partnership (GWP), the Organisation for Economic Co-operation and Development (OECD) and other key international organisations. Water security is defined in five key dimensions, reflecting the main elements of IWRM, with poverty reduction and governance as crosscutting perspectives. All dimensions need to be addressed for long term sustainable development. The five dimensions are: i) Household Water Security; ii) Economic Water Security; iii) Urban Water Security; iv) Environmental Water Security and v) Resilience to Water-Related Disasters (for further discussion & operational methods of measuring Water Security through 54 indicators, see van Beek et al, GWP, 2014).

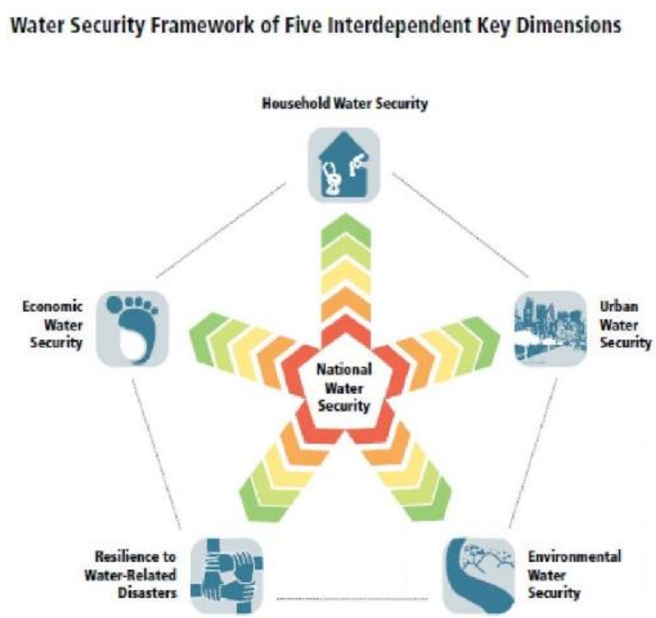

Figure 5.2: Asian Water Development Outlook (ADB 2013)

[22] Flood risk consists of three generic components: 1) flood probability; 2) degree of exposure of people and assets (flood extent, water depth, flow velocities); and 3) vulnerability of the people and assets.

In this section, a first assessment is provided of potential measures and strategies for further development in the BDP with specific reference to water security. The measures include both infrastructure and institutional measures and strategies.

- *Enhanced water use efficiency and water productivity* through precision water management in Irrigation and FCDI areas, including technologies such as use of remote sensing data on crop productivity (see e.g. the results of the Project Sat4Crops, supported by the Dutch Partners for Water Programme), soil moisture sensors, advanced –pressurised - irrigation technology (pressurised; drip and sprinkler), irrigation water management software (see e.g. the pilots and projects implemented under the 'More Crop per Drop' programs worldwide) and crop variety improvement to enhance both productivity and resilience. In this strategy, the public sector plays an enabling role (including both the water and agriculture sectors) and supports private sector parties in innovation and business development.

Contributing to: Economic *Water Security*, *Household Water Security*

- *Integrated water resource management at (sub-)catchment level*, including the development of detailed water balances, (real-time) technologies and institutional arrangements that facilitate integrated water resource planning and operation. Planning and integrated operation will enhance the synergies between the operation and management of polders and schemes and mitigate against negative impacts on other (downstream) areas, environment and sectors. Integrated water management should include a strong participation from the various categories of beneficiaries and stakeholders, including environmental, fisheries, gender and poverty concerns. Using advanced ICT, monitoring and modelling will support the fine-tuning and balancing of interests between the various categories of stakeholders within these FCDI areas. Asset Management at a pilot scale at polder and embankment level and up scaling to all large schemes in the country would be a sub-strategy. Twinning arrangements with operational water management organisations that are already practicing such integrated planning and monitoring approaches, such as e.g. Dutch Regional Water Authorities, should be explored. This strategy builds on the public sector, including organisations such as WARPO, BWDB and LGED but also creates space for private – Non-Government initiatives.

Contributing to: *Environmental Water Security*, *Economic Water Security*

- *Water resource infrastructure and technology development*. Whereas this strategy is mostly a continuation of previous (FCDI) Water Resource, Water Supply and Water Treatment development strategies, innovation would be sought by considering integrated objectives (IWRM and Water Security) and by – from the onset – considering the future management, business development, cost recovery, operation and maintenance whilst designing and commissioning such development. A sub-strategy is needed to support Industries and Urban areas to make the transition to zero- or minimal pollution, through technology innovation, clustering industry types in dedicated zones with tailored treatment facilities, and a gradual phasing in and enforcement of discharge norms and permits for all discharges. Integrated assessments would be used (see below under *development of integrated modelling*) to prioritise the already identified infrastructure schemes (in e.g. the NWMP and other Sector Plans and Strategies). A key need would be the development of *Water Treatment Infrastructure and Technologies for Wastewater Reuse, Desalinisation and Arsenic removal.*

Contributing to: *All Water Security Dimensions*

- Develop the potential for *Managed Aquifer Recharge* in the *Coastal area* and the *North-west/North-central* regions to augment fresh water supplies for households and communities in a sustainable manner. This could a variety of techniques that have been tested world-wide. Further develop advanced (3-D) groundwater modelling for the whole coastal area and enhanced estimation of sustainable yields in the groundwater areas with falling groundwater tables. The Public sector, through DPHE, BWDB and the District Authorities would take the

Contributing to: *Household Water Security*, *Environmental Water Security*

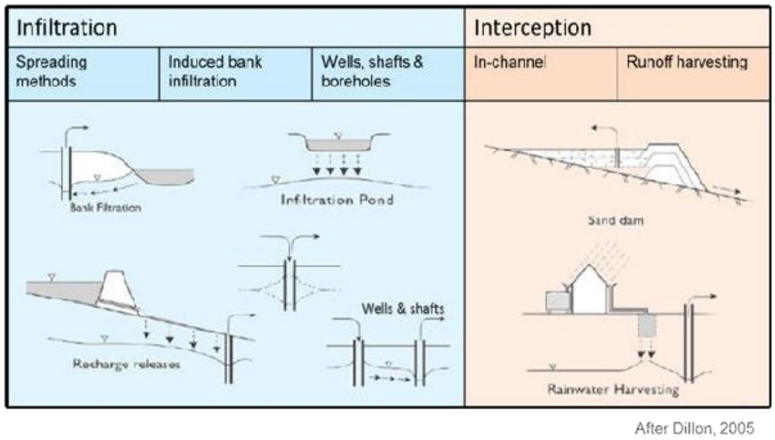

Figure 5.3: Examples of MAR techniques[23]

- *Design, test and replicate green adaptation strategies* that make use of and enhance natural bio-physical processes and serve multiple goals. They reduce flood risk, but also enhance nature. Examples of green adaptation strategies are mangrove forest and floating marshes to decrease the impact of waves, green roofs and retention zones in urban areas, but also green water treatment (such as helophyte filters). In addition, and based on integrated assessment at regional and catchment level, the re-connecting of floodplains and wetlands (beels) for environmental restoration, capture fisheries development, flood retention and groundwater recharge should be taken up.

Contributing to: *Environmental Water Security*, *Urban Water Security*, and *Resilience to Water-Related Disasters*

- *Development of a social safety net* to provide socio-economic security to vulnerable groups affected by floods. Extreme floods are extremely damaging at individual household or area (town) level. Viewed at national level however, the damage is much less. A safety net (= a compensation fund) would allow for compensation of households affected disproportionately. This would be especially beneficial to the poorest people in Bangladesh. Especially the Public and NGO-sector, and possibly the Insurance sector, would take the lead in this strategy.

Contributing to: *Urban Water Security*, and *Resilience to Water-Related Disasters*

- Highly developed *Early Warning Systems and Strategies for Floods and Droughts*, including spatial planning that accounts for flood risk by using flood zonation and drought vulnerability maps and developing area-based flood and drought safety plans. Vulnerable areas, in terms of loss of life, poverty, critical infrastructure

[23] Rainwater (rooftop) harvesting is tested in the Barind tract, with positive results. See also: Mapping of Groundwater Recharge Potential in Bangladesh, Prof. Chowdhury Sarwar Jahan, Department of Geology and Mining, University of Rajshahi, undated

and economic value, would receive particular protection in this strategy. This would include enhancing the reliability of forecasts to 5 days[24], improving outreach and communication to all communities (by using both internet based and push sms technologies and developing local level disaster information centres incorporating real-time data and model forecasts). This strategy would include upgrading of the capacity and resources of key institutions working in this field such as the FFWC, DDM, LGIs and Agriculture development organisations and NGOs (such as BRAC and others) working in this field. Developing controlled flooding in the Northern regions of the countries (North-East, Central and West) –based on up-to-date modelling and (near) real-time information would be sub-strategies. Development of commercial business models for early warning systems on floods and droughts, which may include the setting up of flood and crop insurance schemes would be a sub-strategy. A strong combination of locally tailor made and Public-Private partnerships would take the lead in this strategy.

Contributing to: *Resilience to Water-Related Disasters*, *Economic Water Security, Environmental Water Security*

- Further and accelerated *development of integrated modelling* and data collection/monitoring instruments, including full 2-D flood modelling, water quality and water demand modelling, open source applications, including Open Earth and Global Data, participatory monitoring and data collection and integrated meta-modelling (see also Chapter 5) to carry out integrated assessments of scenarios, strategies and measures at national, regional and local level, across all water related sectors. Tools such as the Flood Impact Assessment Tool (FIAT), based on a combined analysis of land use, asset value and damage functions and flood hazard mapping, developed for the Netherlands, can support decision-making in this respect. This would include highly visual touch/map table applications as well as smartphone applications and use of GPS technologies. The Public Sector would enable Private Sector, and Knowledge Institutions to take the lead in this strategy and ensure sharing of data. Specific innovation programs, such as the European Climate KIC program, may serve as a source of inspiration in designing this strategy.

Contributing to: *Economic Water Security, Resilience to Water-Related Disasters*, *Household Water Security, Environmental Water Security*

- *Public-private partnerships to manage (FCD) Irrigation schemes*, allowing for financial autonomy and providing incentives for technological improvement of water resource management in these areas. Typically, such a strategy would involve both Public and Private partners, with the Public Sector focussing on its role in developing the enabling legal environment. Well defined risk sharing modalities are a key success factor. In preparation, in-depth analysis of key success factors for sustainable WMOs and development of a nation-wide WMO strengthening program would be carried out. This would include participatory monitoring.

Contributing to: *Economic Water Security, Resilience to Water-Related Disasters*, *Household Water Security, Environmental Water Security*

[24] A mathematical model for generating flash flood forecasts for the NE region with 2 days lead time has been developed by IWM. The model is simulated for 7 days prior to date of forecast (hindcast) and 3 days after date of forecast. The model uses real time rainfall data in the public domain and FFWC / BWDB and rainfall prediction produced through a simulation of weather research forecast (WRF). At present, FFWC issues forecast bulletins with 2 days lead time.

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