DEVELOPMENT OF AN INTEGRATED RIVER BANK EROSION MANAGEMENT FRAMEWORK IN TIDAL PLAIN

By

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It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

.....

Faruq Ahmed Mohiuddin

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ABSTRACT

From times immemorial, near bank floodplains have been the preferred locations for human settlement, agricultural development, growth-centers and socio-economic development. It is because of their proximity to rivers, guaranteeing rich soils, abundant water supplies and means of water-way transport. Unfortunately, some of the river banks erode and cause considerable loss of lives, livelihoods, property, adverse impacts on the economy and people's safety. Therefore, living in the erosion vulnerable near bank floodplains is a challenge.

In Bangladesh, generally bank protection works are considered when the eroding channel seriously intrudes into areas where substantial economic development has taken place and hence significant damage might occur. Usually after severe bank erosion a project would be quickly planned, designed and implemented. The erosion problem and its solution seeming self-evident without giving any thought to the impact of such solutions that would have on upstream and downstream areas. Thus, present erosion protection practices have largely been focused on reducing erosion vulnerability through protecting the river bank only on structural solutions.

However, any complete framework for river bank erosion management that could be practiced in Bangladesh is yet to be developed. Although a few frameworks exist that cover one or two aspects of river bank protection work, these have been practiced in a piecemeal way in Bangladesh. But the full benefits of the project by protecting the bank were never achieved. Sometimes the structural measures adopted in these projects have been damaged partly or fully. Consequently, recognizing the importance of non-structural and structural measures, this research has been taken up to develop an integrated river bank erosion management (IRBEM) framework, which addresses all relevant aspects of river bank erosion management.

In this context, it is needed to be understood not only in the scientific and technological methodologies but also in institutional management and skills with community involvement covering techno-socio-economic aspects. The relevant aspects of IRBEM are technological management, social management, risk management, environmental management, economic management and institutional management. Detail approach and methodology for individual aspects have been developed to recommend an IRBEM framework by integrating parameters of techno-socio-economic processes. By developing six individual schematic frames for each aspect, an integrated framework has been developed based on a set of linked parameters to address the techno-socio-economic impacts on river bank erosion management using multi-criteria analysis and sensitivity analysis of parameters.

The six individual schematic frames considering all functional outcome stages have been developed based on their functional relationship between outputs of the particular aspect and inputs of other aspects. In addition, all schematic frames establish an interactive approach for pre-erosion and post-erosion management operations with erosion emergency management operations by introducing the monitoring and evaluation techniques.

An integrated framework has been developed by linking common parameters of the six individual frames through sensitivity analysis and multi-criteria analysis. The

functional form of local erosion management association (LEMA) has been addressed for ensuring the participation of the affected people. The erosion emergency operations with respect to IRBEM aspects including its time horizon have also been developed. The final IRBEM framework establishes five outcome stages: erosion assessment, risk assessment, mitigation measure, design and implementation. At least two or more aspects have been integrated to achieve the indicator of each outcome stage. In this framework, a procedure has also been developed for selecting the adaptive adequate erosion mitigation measures for two separate management operations: (a) pre-erosion and post-erosion, and (b) erosion emergency, where emergency work has been integrated with monitoring and evaluation.

An implementation procedure of IRBEM framework has been developed for selecting the suitable adaptive erosion mitigation measures. IRBEM plays a key role in selecting the suitable mitigation measures on the basis of risk-safety, trade-off decisions and conflict resolutions. This framework has been tested in the ChanderChar erosion vulnerable area along the Nabaganga River. It is found that suitable erosion mitigation plan can be selected considering all aspects of river bank erosion management. Moreover, the challenges in operationalizing the IRBEM framework have also been identified that can be overcome following the procedure developed in the schematic frame of individual aspects. This new IRBEM framework can be further applied in other tidal plain locations. This can also be modified for application in non-tidal plain locations.

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Acronyms and Abbreviations

1D	One-dimensional
2D	Two-dimensional
ADB	Asian Development Bank
AG	Advisory Group
ALHT	Annual Lowest High Tide
APFM	Associated Programme on Flood Management
ASCE	American Society of Civil Engineers
B/C	Benefit-cost
BCAS	Bangladesh Centre for Advance Studies
BWDB	Bangladesh Water Development Board
CB	Crossing Boundaries
CBA	Cost-benefit analysis
CBD	Convention on Biological Diversity
CEGIS	Centre for Environment and Geographic Information System
DHI	Danish Hydraulic Institute
DHW	Design High Water
DLWL	Design Low Water Level
DWL	Design Water Level
EC	European Commission
EIA	Environmental Impact Assessment
EIRR	Economic Internal Rate of Return
FEMA	Federal Emergency Management Agency (United States)
FAP	Flood Action Plan
FGD	Focus Group Discussion
FPCO	Flood Plan Coordination Organization
FS	Factor of Safety
GDP	Gross Domestic Product
GoB	Government of Bangladesh
GWP	Global Water Partnership
HEC-RAS	Hydrologic Engineering Centre – River Analysis System, a computer program that models the hydraulics of water flow
IEC	Important Environmental Components
IEE	Initial Environmental Examination
IFM	Integrated Flood Management
IRBEM	Integrated River Bank Erosion Management
IRR	Internal Rate of Return
ISDR	International Strategy for Disaster Reduction
ISPAN	Irrigation Support Project for Asia and the Near East
IWM	Institute of Water Modelling
IWFM	Institute of Water and Flood Management
IWRM	Integrated Water Resources Management
JMREMP	Jamuna Meghna River Erosion Mitigation Project
LAG	Local Ad-hoc Group
LEMA	Local Erosion Management Association
LGED	Local Government Engineering Department
LWL	Low Water Level
M&E	Monitoring and Evaluation

MCA	Multi-criteria Analysis
MEA	Millennium Ecosystem Assessment
MIKE21C	A Two-dimensional Morphological Modelling Tool
MoF	Ministry of Finance
MoWR	Ministry of Water Resources
NDGs	National Development Goals
NGO	Non-Government Organization
NPV	Net Present Value
NWMP	National Water Management Plan
NWPo	National Water Policy
O&M	Operation and Maintenance
PRA	Participatory Rural Appraisal
PRSP	Poverty Reduction Strategy Paper
RLAT	Rapid Legal Assessment Tool
SA	Stakeholder Analysis
SaciWATERs	South Asian Consortium for Interdisciplinary Water Resources Studies
SAWA	South Asian Water Association
SC	Silt-clay content
SEA	Strategic Environmental Assessment
SHW	Standard High Water
SLW	Standard Low Water
SPARSSO	Bangladesh Space Research and Remote Sensing Organization
SVI	Social Vulnerability Index
SWOT	Strength Weakness Opportunity Threat
UN	United Nations
UNFCC	United Nations Framework Convention on Climate Change
UP	Union Parishad
USA	United States of America
WaRPO	Water Resources Planning Organization
WB	World Bank
WMO	World Meteorological Organization

Notations

The following symbols are used in this thesis:

a	=	Bed material porosity;
b	=	outer bank erosion width;
B	=	Water surface width;
C	=	Chezy roughness coefficient;
C'_L	=	Coefficient of lift force when using friction velocity;
C_D	=	Drag coefficient;
c_b	=	near bed concentration of moving sediment;
c_d	=	Cohesion of bank material above the water surface;
c'	=	effective cohesion;
D_n	=	Deposition rate;
E	=	Erosion coefficient;
E_r	=	Bank erosion rate (lateral);
E_v	=	erosion volume;
E_n	=	Entrainment rate;
g	=	Acceleration of gravity;
h	=	Local water depth;
H	=	Bank height at the critical condition;
H'	=	Bank height above the zone of lateral erosion;
h_b	=	Height of the bank above the water level;
I	=	Surface slope;
$K = Y / H$	=	Ratio of crack depth to bank height;
k	=	Erodibility coefficient;
M	=	Manning roughness coefficient factor;
n	=	Manning roughness coefficient;
p	=	Frequency;
Q_p	=	Critical discharge for bank failure corresponding to eroding velocity;
S	=	Near bank sediment transport;
S_x	=	Total sediment transport in x-direction;
S_y	=	Total sediment transport in y-direction;
t	=	Time;
u_{*b}	=	Friction velocity at the bank surface;
u_{*bc}	=	Critical friction velocity for entrainment;
v	=	Depth-average flow velocity;
V_s	=	Mass volume of eroded sediment by entrainment;
V_{sn}	=	Sediment particle escape velocity from the bank normal to the surface;
W_t	=	Weight of failure block;
Y	=	Tension crack depth;
z	=	Local bed level;
(x, y)	=	Cartesian coordinate system;
α	=	Angle of bank;
α_c	=	Angle of failure plane;

$\alpha_1, \beta_1, \gamma_1$	=	Calibration coefficient specified in the MIKE21C model;
γ	=	bulk soil unit weight;
γ_s	=	Specific weight of bank material;
ϕ	=	Angle of repose;
ϕ'	=	effective internal friction angle;
ω	=	settling velocity of a spherical sediment particle;
η	=	Probability that flow discharge is greater than the critical discharge of bank failure;
ΔS_e	=	Lateral sediment supply from bank erosion;
Δn	=	Width of cell next to bank line;
ΔB	=	Distance of bank retreat due to bank failure / width of failure block;
$\Delta T = T_s + T_f$	=	Total time required for both basal erosion and bank failure;
ΔZ	=	Depth of vertical degradation;
ρ	=	Density of water;
ρ_s	=	Density of sediment particles;
τ	=	Bed shear stress;
τ_c	=	Critical shear stress;
τ_o	=	Shear stress at the toe of the bank slope;
τ_{bank}	=	Applied bank shear stress;
τ_{ex}	=	Excess shear stress;
SF_{bank}	=	Proportion of the total cross-sectional shear force acting on the bank;
P_{bed}	=	Wetted perimeter of the bed;
P_{bank}	=	Wetted perimeter of the bank;

CHAPTER ONE

INTRODUCTION

1.1 Background

From times immemorial, near bank floodplains have been the preferred locations for human settlement, agricultural development, growth-centers and socio-economic development. It is because of their proximity to rivers, guaranteeing rich soils, abundant water supplies and means of water-way transport. Unfortunately, some of the river banks erode and cause considerable loss of lives, livelihoods, property, adverse impacts on the economy and people's safety. Therefore, living in the erosion vulnerable near bank floodplains is a challenge.

Bangladesh is prone to natural disasters such as floods, cyclones, river-bank erosion and droughts. While people living in riverine areas are more exposed to the dangers of natural disasters, poor households suffer more than non-poor households. Many poor are settled in high risk areas and lack of resources to afford disaster proof housing. Water related hazards do not, however, impact all sections of the community equally or uniformly. Several water related hazards have been identified for the study area: floods, drought, cyclones, salinity, river-bank erosion, ground water contamination (including arsenic), surface water pollution, water logging / drainage congestion, reduced dry season flows from the Ganges through the Gorai River, sedimentation of rivers and canals, lack of safe drinking water, loss of biodiversity and conflicts of interest.

These hazards initially degrade the environment and natural resources within an area. The poor then fall victim to numerous vulnerabilities, which eventually leads to a widening of the hardcore poverty margin. The capacity of individuals and society to cope these hazards is then weakened which exasperates the vulnerability of the poor (BWDB, 2004). The river-bank erosion along the bank of the Nabaganga River has only been taken up for this research out of several identified hazards. The vicious cycle of river bank erosion is illustrated in **Figure 1.1**.

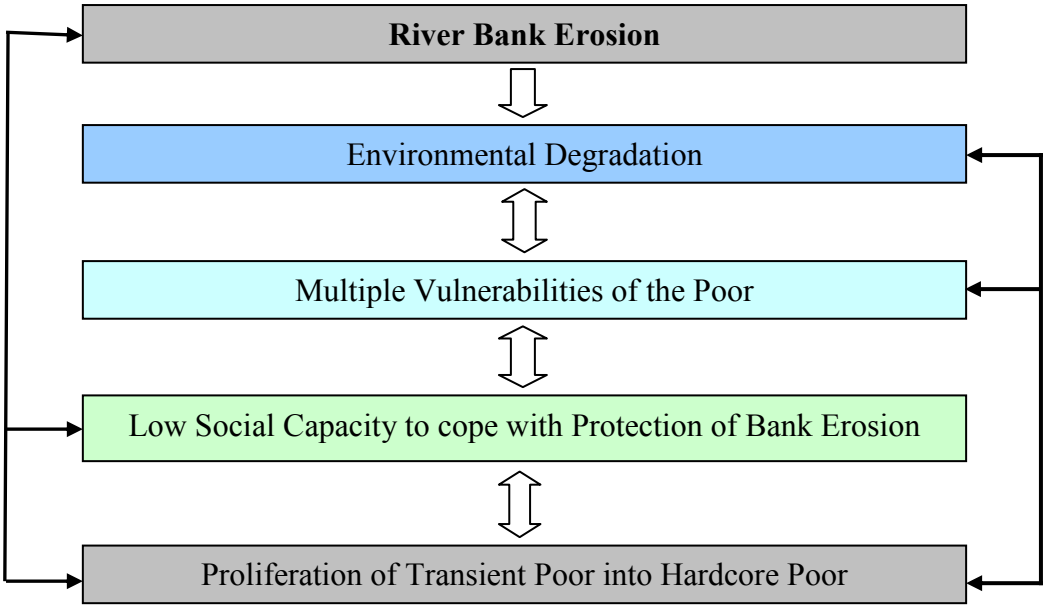


Figure 1.1: Vicious cycle of river-bank erosion and poverty

The river bank erosion is a water related hazard for all the occupational groups residing along with the riverine bank. River bank erosion causes loss of land, loss of homesteads, and embankments/rural infrastructures. Loss of land and homesteads leads the poorer groups to reside on the embankments and beside the rivers in impoverished conditions. On bank of many rivers, poorer households often cultivate in the unutilized government low lands beside the rivers (BWDB, 2004). Due to the river bank erosion these sporadic cultivation remain highly vulnerable to erosion. The complex relationships between river bank erosion and its consequences are shown in **Figure 1.2**.

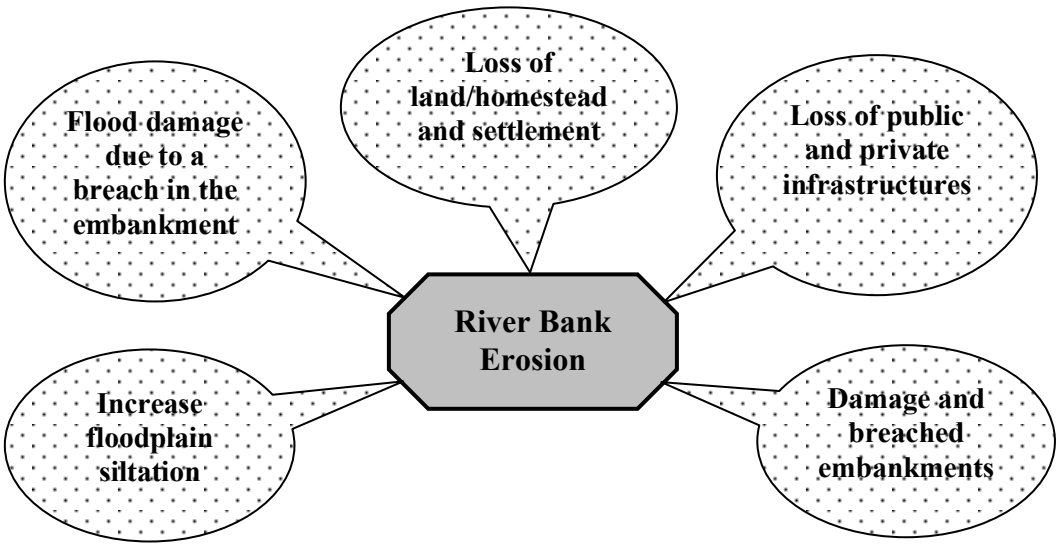


Figure 1.2: The river bank erosion and its consequences for erosion vulnerable communities

River bank erosion management involves the transformation of natural hydrological resources into a managed resource by minimizing the land and water impacts at the erosion vulnerable banks. Traditionally, river bank erosion protection practiced in Bangladesh has essentially problem driven. Usually after severe bank erosion a project would be quickly planned, designed and implemented. The erosion problem and its solution seeming self-evident without giving any thought to the impact of such solutions that would have on upstream and downstream areas. Thus, present erosion protection practices have largely been focused on reducing erosion vulnerability through protecting the river bank only on structural solutions. Some of them could be complemented with non-structural measures, such as river bank erosion prediction and land use regulations. Moreover, any river bank erosion management framework that could be practiced in Bangladesh is yet to be developed. In this context, it is needed to be understood not only in the scientific and technological methodologies but also in institutional management and skills with community involvement covering socio-economic aspects. During the data collection process, the following five constraints or deficiencies have been identified in traditional bank erosion protection practices in Bangladesh:

- *Deficiency of information and understanding*: recognition that land and water has a value in all its competing uses, and incorporation of this concept in the planning, implementing process; compilation of existing data;
- *Deficiencies of inter-ministerial governance*: existence of network of institutions, policy makers, managers, stakeholders and scientists;
- *Deficiency in capacity*: availability of required technical and managerial skills;
- *Deficiencies in land and water management options*: development of coping and adaptation mechanisms, ways and means of addressing mitigation measures;
- *Deficiencies in stakeholder involvement*: involvement of the stakeholders from the outset in planning and development;

In response to bank erosion and its adverse impact on water resources management and sustainable development, a new paradigm of river bank erosion management concept is introduced. With this vision a conceptual framework (see **Figure 1.3**) has been developed to assess what types of challenges are facing following the erosion hazard

sequence. The new paradigm has been incorporated through control stage considering not only in the scientific and technological methodologies but also in institutional management and skills by integrating techno-socio-economic evaluation. The interdisciplinary approach has been introduced in the control stages such as technological, social, risk, environmental, economic and institutional aspects. Some of the suggested activities in the control stage can modify the hazard sequence and some can block hazard sequence. By combining the activities illustrated in the control stage and by integrating the parameters of each aspect, an integrated river bank erosion management concept has been developed.

It is vital to understand the interplay between bank erosion, mitigation measure process and poverty in order to establish the management technique which includes current, future development planning and implementation. Otherwise, the poor management practice leads to, or has the potential to, increase vulnerability and risk. In reality, the appropriate mitigation measure (solution) is necessary for a community, otherwise few multipliers is exposed to many disturbances, some of which may have a greater impact than bank erosion. With this view, the new concept aims at changing the psychology and emphasize on “erosion control” to the necessity to “manage the erosion” by shifting the focus from a reactive to a more proactive response. Accordingly, this research has been carried out to develop an Integrated River Bank Erosion Management (IRBEM) framework which addresses the physical, social, risk, environmental, economic and institutional aspects of bank erosion. The principles of IRBEM, therefore, will include the following:

- adopting a vulnerable reach approach to bank erosion management;
- bringing interdisciplinary approach to bank erosion management;
- reducing vulnerability and risks due to bank erosion;
- enabling community participation;
- implementing resettlement plan for the displaced people; and
- institutional capacity building.

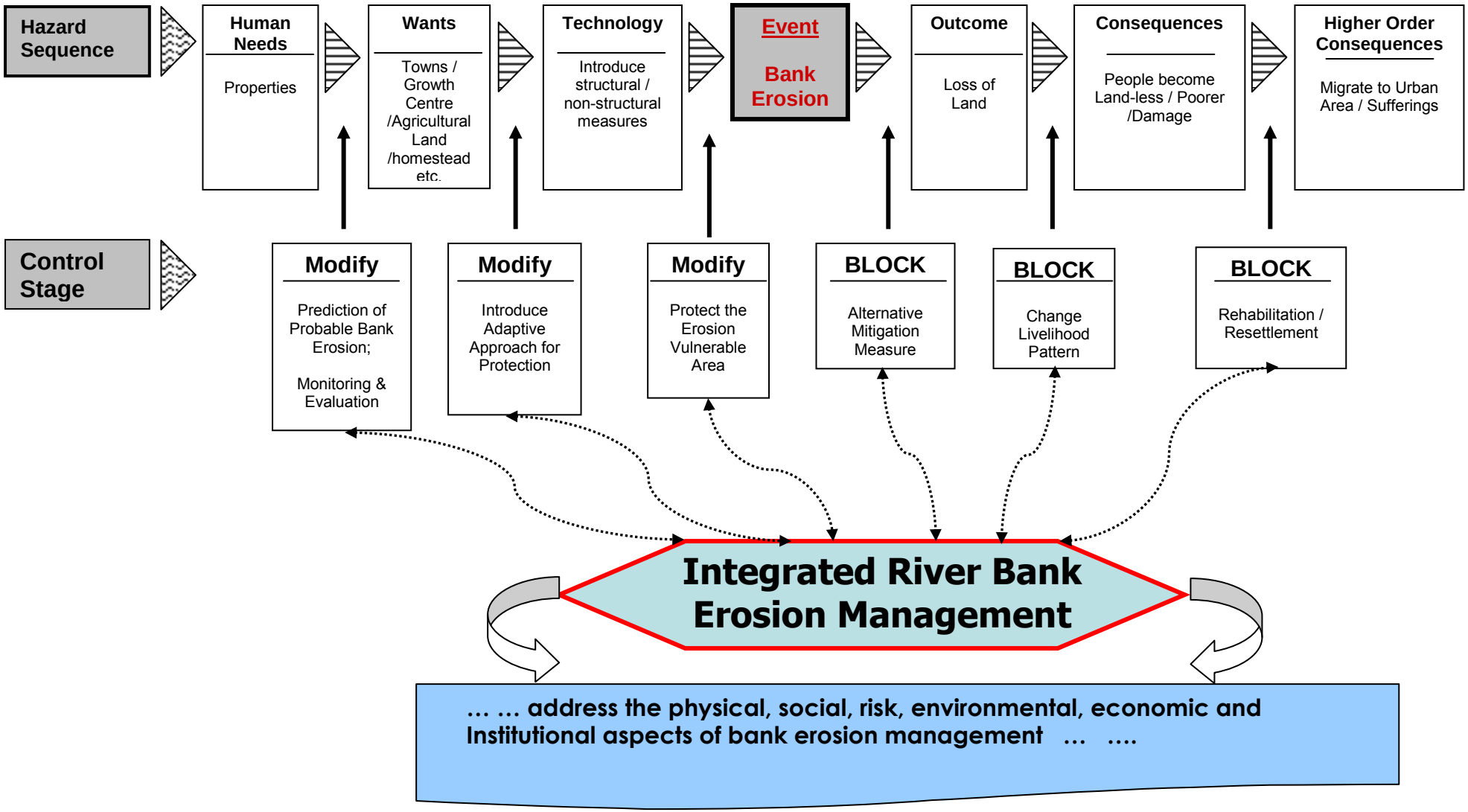


Figure 1.3: The conceptual framework of river bank erosion management with hazard sequence and control stage

1.2 Objectives

General Objective:

The overall objective is to develop a river bank erosion management framework by integrating parameters of techno-socio-economic processes of various alternative measures through an institutional frame to minimize the river bank erosion damages.

Specific aims:

The following are specific aims to achieve the overall objectives:

i. Develop the procedure to assess and prediction of vulnerable eroded reach (i.e., identification of erosion prone banks – locations, length & severity) to be brought under erosion management framework;
ii. Identify and categorize the associated risk integrating parameters of techno-socio-economic processes and develop a procedure for risk management plan; and
iii. Develop procedure for selecting the adaptive adequate erosion mitigation measures under the erosion management framework for identified erosion vulnerable banks during (a) pre-erosion management operations, (b) erosion emergency management operations and (c) post-erosion management operations.

1.3 Scope of Work

The river bank erosion management issues have been addressed with an integration of key parameters of different aspects following the procedure of interdisciplinary approach within the context of IWRM. Accordingly, scope of work has been devised to deal with the following management issues:

- Prediction process of river bank erosion rate and its validation with real time data;
- Analysis of the applicability of prediction methods;
- Determination of types of risk mitigation measures and its applicability;
- Assessment of hydraulic design parameters and its design consideration;
- Devising an implementation plan;

- Social perception on river bank erosion;
- Social impact indicators contributing to vulnerability;
- Social vulnerability index;
- Stakeholder mechanism;
- Understanding of the bank erosion risk including its vulnerability;
- Erosion risk management operations;
- Bank erosion emergency response;
- Post-erosion recovery and rebuilding;
- Environment and sustainable development;
- Morphology and ecology of the river bank floodplains;
- River bank erosion management interventions and ecosystems;
- Economics of river bank floodplains;
- Cost-benefit analysis;
- Economic evaluation techniques;
- Fund allocation of river bank erosion management programmes;
- River bank erosion management policy;
- Institutional mechanisms with legal reform processes;
- Pre-erosion and post-erosion management operations; and
- Erosion emergency management operations.

1.4 Expected Outcome

This research has been introduced/recommended a new paradigm of integrated river bank erosion management (IRBEM) framework. The IRBEM follows the procedure of interdisciplinary approach which includes techno-socio-economic processes through an institutional concept for protection of a vulnerable eroded river bank.

CHAPTER TEN

INTEGRATED RIVER BANK EROSION MANAGEMENT (IRBEM) FRAMEWORK

10.1 Integration of Schematic Frame of Individual Aspects

In response to river bank erosion and its adverse impacts on water resources management and sustainable development, a new paradigm of river bank erosion management has been addressed (Mohiuddin et al, 2011). The river bank erosion management issues have been integrated by compiling the sensitive indicators of six individual aspects, i.e. technological, social, risk, environmental, economic and institutional aspects. An integrated framework has been developed by linking common parameters of the six individual frames of different aspects through multi-criteria analysis (MCA) and sensitivity analysis. Finally, a procedure has been developed for selecting the adaptive adequate erosion mitigation measures for (a) pre-erosion and post-erosion management operations and (b) erosion emergency management operations.

10.1.1 Pre-erosion and post-erosion management operations

Sensitivity analysis of variables:

The sensitivity analysis means a technique used to determine how different values of an independent variable will impact a particular dependent variable under a given set of assumptions. Sensitivity analysis has been carried out by attempting three technological aspects, i.e. (a) actual extent of bank erosion, (b) predicted extent of bank erosion and (c) adopting exposure to determine the impact of actual outcome of a particular variable that was previously evaluated. By creating a given set of scenarios of individual aspects from sample survey data at ChanderChar and Noagram area, determine how changes in one variable(s) will impact the target variables. In general, sensitivity analysis has been carried out qualitatively to investigate the robustness of the IRBEM fulfilling the following purposes:

- to support decision making or the development of recommendations for decision makers (i.e. testing the robustness of survey result);

- for enhancing communication from planners to decision-makers (i.e. by making recommendations more credible, understandable, compelling or persuasive);
- to increase understanding of the system (i.e. understanding relationships between input and output variables of different aspects);

The indicators setting in sensitivity analysis has strong identity of individual aspects. In sensitivity analysis, one looks at the effect of varying the inputs of technological aspect on the output of other aspects itself. In all aspects one strives to obtain information from the developed integrated river bank erosion management framework. In sensitivity analysis, there is a critical tradeoff between how careful a planner is in exploring the input evaluations and how wide the resulting inference may be. A form of organized sensitivity analysis has been designed in this research by identifying neighborhood alternative assumptions to be credible and corresponding inferences is narrow enough to be useful. Finally, a set of integration (see **Table 10.1**) between different aspects of river bank erosion management has been done to recommend type, extent of mitigation measures for implementation. The integration set-out among the different aspects following outcome stages: planning, develop plan & adopt, risk identification, exposure analysis, economic and financial analysis, type of mitigation measures, design and implementation.

Multi-criteria analysis:

Multi-criteria analysis is a balancing approach to evaluate the qualitative field survey data/information for a planner/decision-maker. In this research it follows two-stage procedure, i.e. (i) identify a set of goals and its trade-offs between the goals achieving a known strategy, (ii) identify "best" strategy by ranking weights (scores) to the various goals. It involves judging the expected performance of each erosion management aspects against a number of criteria. For example, (a) erosion zone may be classified as low erosion zone, medium erosion zone and high erosion zone, (b) human exposure may be classified as erosion prediction, preparedness, response, recovery, resettlement and structural measures, and (c) preference of mitigation measures may be classified as long-term preference (non-structural), short-term preference (structural & non-structural) and immediate preference (structural).

Table 10.1: Integration between different aspects of river bank erosion management

Pre-erosion & Post-erosion Management Operations:

Aspects / Outcome Stages	Technological	Social	Risk Management	Environmental	Economic	Institutional
Planning	○ Macro: identification of probable erosion prone area ○ Micro: prediction of river bank erosion rate, extent & severity	○ Assessment of socio-economic status ○ Social factors contributing to vulnerability	○ Conditions of vulnerability of the elements at risk ○ Exposure of human activity	○ Assessment of environmental indicators	○ Assessment of real erosion damage data ○ Establish erosion damage relation	○ Erosion hazard maps ○ Land use planning
Develop Plan & Adopt (capacity building)	Erosion Early Warning sub-plan	Evacuation sub-plan Resettlement sub-plan Recovery sub-plan	Risk management sub-plan	Strategic environmental impact assessment sub-plan	Strategic damage assessment sub-plan	Local erosion management association (LEMA) plan
Risk identification	Identify & categories the risk zone "high", "medium" & "Low"					
Exposure analysis	Adopting exposure (structural / non-structural)					Define law/policy
Economic and financial analysis					○ Economic viability indicators – NPV, BC ratio & EIRR	○ Allocation of fund
Type of mitigation measures	○ **Assessment & evaluation of options** ○ **Trade-offs**					
Design	Hydraulic design parameters	Assess protection needs socially acceptable		Asses mitigation measure environment friendly	Asses mitigation measure economically viable	Suggest adequate erosion mitigation measures
Implementation	**Recommend type, extent of mitigation measures for implementation**					

The essence of MCA has been described by making a performance matrix based on the surveyed data/information on individual aspects with several rows and columns. Each row describes the responses of each question and each column describes criterion or performance dimension. Accordingly, scores for each question with respect to each criterion are assigned. These scores are supposed to represent performance indicators and are evaluated through specific value functions for each criterion as based on scientific knowledge. In this research, weights are assigned to each criterion and a scale of 1 to 10 is adopted. Thereafter, a weighted average score is evaluated. This average provides the overall performance of indicator of each question. On the basis of the cumulative average score of each erosion management aspect follows classification as below (see **Table 10.2**).

Table 10.2: Intuitive judgments of MCA

Identified field/class	Category	Average score
Erosion zone	Low Medium High	0 – 4 4 – 6 6 – 10
Human exposure	Awareness Erosion prediction & warning Preparedness, Recovery, Resettlement	0 – 4 4 – 6 6 – 10
Preference of mitigation measure	Long-term Short-term Immediate	0 – 4 4 – 6 6 – 10

A sample survey has been carried out within the erosion victim people at ChanderChar and Noagram village along the bank of the Nabaganga River. There are around 150 households at Chanderchar area and 200 households at Noagram area, who are directly erosion victim people, have been found respectively. Out of them 15 to 20 samples (households) in each area have been interviewed and collect the qualitative information by filling a questionnaire, generating the data through observation of respondents and through some combination of this procedure. During the data collection approximately 10% of the total households have been interviewed to make the sample size representative and make sure the collected data/information provides saturation.

Moreover, six focus group discussions (FGD) among the homogeneous group of erosion affected people at the two sites, i.e. ChanderChar and Noagram has been

carried out to validate the previously collected data. In addition, a sample survey has been carried out among the decision-makers/planners of BWDB and the sample size has been determined based on the working professionals of planning, design and hydrology. In this regard, no FGD is possible. The inference has been drawn from the collected data through interviews. The survey questionnaire form for six individual aspects is given in **Appendix-A** with an example of the scoring method. The following inferences (see **Table 10.3**) have been drawn from the qualitative data analysis in-terms of erosion category, human exposure, preference of mitigation measures and recommend the type of erosion mitigation measures for implementation.

Table 10.3: Summary of data analysis for individual aspects

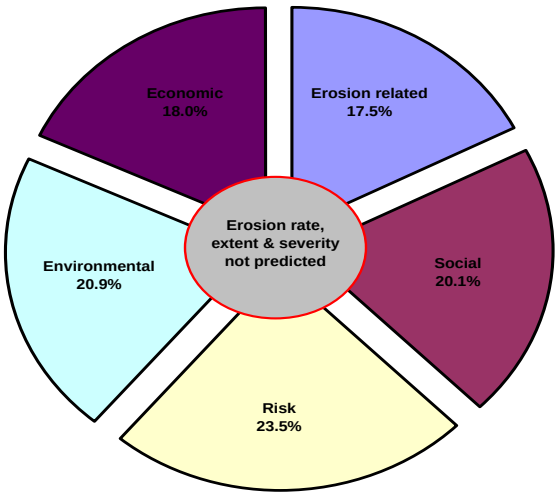
Aspects	ChanderChar Area				Noagram Area			
	Average score	Erosion category	Human exposure	Preference of mitigation measure	Average score	Erosion category	Human exposure	Preference of mitigation measure
Technological	5.6	medium	Erosion forecasting & warning	Short-term	5.6	medium	Erosion forecasting & warning	Short-term
Social	7.7	high	Preparedness Recovery	Immediate	7.56	high	Preparedness Recovery	Immediate
Risk management	9.0	high	Resettlement	Immediate	8.8	high	Resettlement	Immediate
Environmental	8.0	high	Erosion forecasting & warning, Recovery	Immediate	7.8	high	Erosion forecasting & warning, Recovery	Immediate
Economic	6.9	high	Recovery Resettlement	Immediate	6.7	high	Recovery Resettlement	Immediate
Erosion related	6.7	high	Erosion forecasting & warning	Immediate	6.8	high	Erosion forecasting & warning	Immediate
Recommend for implementation:	Short-term & Immediate				Short-term & Immediate			

A correlation between individual aspects of integrated river bank erosion management for pre-erosion and post-erosion management operations are given in **Figure 10.1**. The erosion hazards (%) in different aspects have been estimated from the survey (interview/FGD) data following the two technological issues, i.e. (a) bank erosion (rate, extent & severity) not predicted, consider only actual bank erosion (b) bank erosion (rate, extent & severity) predicted, consider bank erosion early warning. The sub-plans of individual aspects in integrated river bank erosion management have been devised based on the estimated erosion hazards. Finally, suggest adequate erosion mitigation measures, recommending type, extent of mitigation measures for implementation.

Pre-erosion & Post-erosion Management Operations:

Integrated River Bank Erosion Management (IRBEM) Aspects

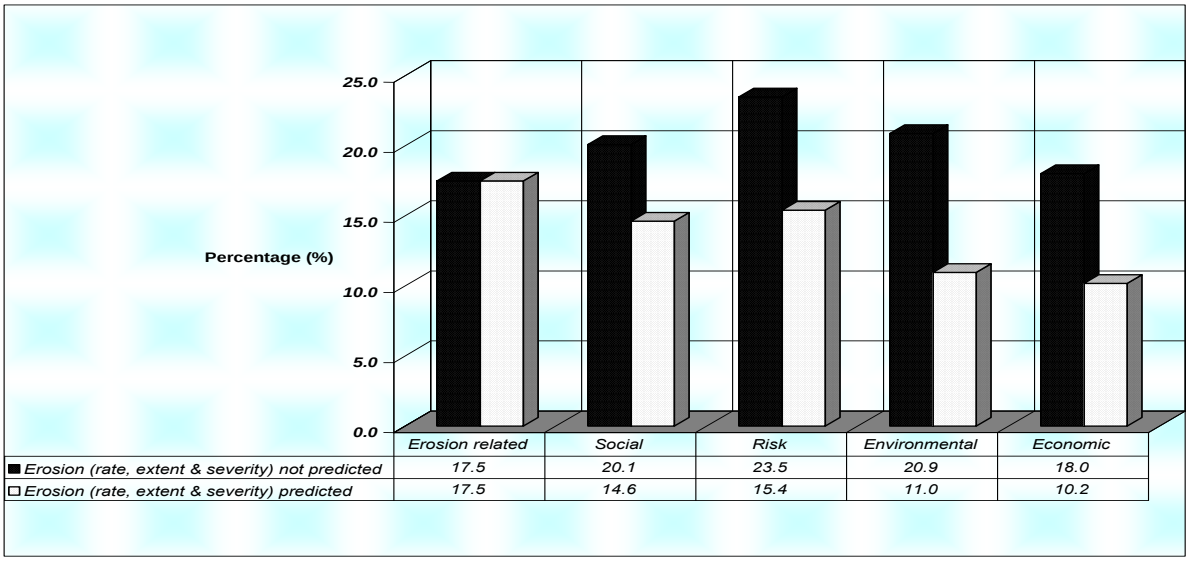
Technological	Social	Risk Management	Environmental	Economic	Institutional
Calculation Prediction of river bank erosion rate, extent & severity	Interview/FGD				Planning Erosion hazard maps



Actual erosion hazards (%) in different

Sub-plans

Erosion early warning	Awareness Evacuation Resettlement Recovery	Risk management	Environmental impact assessment	Damage assessment	Local erosion management association (LEMA)



Suggest adequate erosion mitigation measures
(non-structural or structural)

Recommend type, extent of mitigation measures for implementation

Figure 10.1: A correlation between different aspects of IRBEM

10.1.2 Erosion emergency management operations

Periodic bank erosion creates serious social problems with negative impacts on human lives, livelihoods and economic activity of the society. In this regard, an erosion emergency management operation plays an important role in protecting people and their socio-economic activities in floodplains from erosion. The key components of bank erosion emergency response are erosion early warning sub-plan (using technological aspects), public awareness build-up to protect lives, livelihoods, critical infrastructures; provision of safe shelters including evacuation for the to be affected people; assessment of immediate needs for recovery and provide adequate facilities (using social aspects).

Foreseeable bank erosion is very much inevitable because successful emergency operations depend on the availability and reliability with a lead-time of an early erosion warning system. By predicting the erosion extent, how much area would be in danger in near future could be estimated. The longer the lead time, the more useful the warning is to carry out a number of responses. Warning needs to be provided in an understandable manner following the local language through a legally designated single authority (LEMA). The authority can demarcate the danger line based on the predicted erosion extent as red flag for high-risk zone, pink/orange flag for moderate risk zone and yellow flag for less erosion zones.

During the monsoon, continuous monitoring and evaluation in-terms of flow pattern, flow velocity, erosion and sedimentation processes is required to assess the erosion vulnerability, if needed quick implementation steps needs to be taken under an ad-hoc plan and design. Although, erosion emergency plans are generally developed in parallel with pre-erosion and post-erosion management operations. The most important interactions between the two planning operations take place when emergency work is evaluated through lesson learning. Implementation of emergency operations is complementary, which requires capacity building of erosion affected people. The erosion emergency operations with respect to IRBEM aspects including its time horizon is illustrated in **Figure 10.2**. This figure establishes a relationship between the two processes, i.e. pre-erosion and post-erosion management with emergency management. The most important feature of emergency response is timely and efficient coordination between responsible agencies and local erosion affected people.

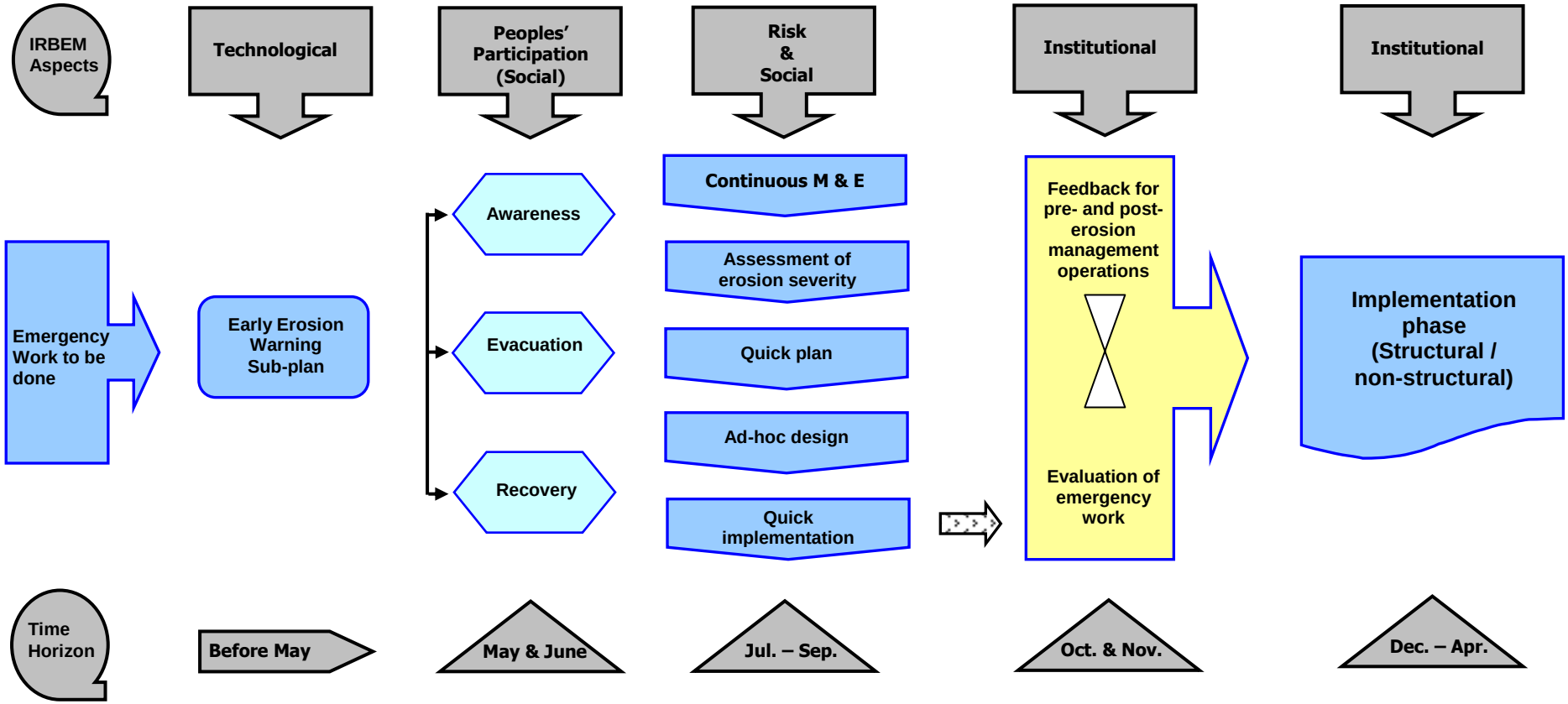


Figure 10.2: The erosion emergency operations with respect to IRBEM aspects including its time horizon

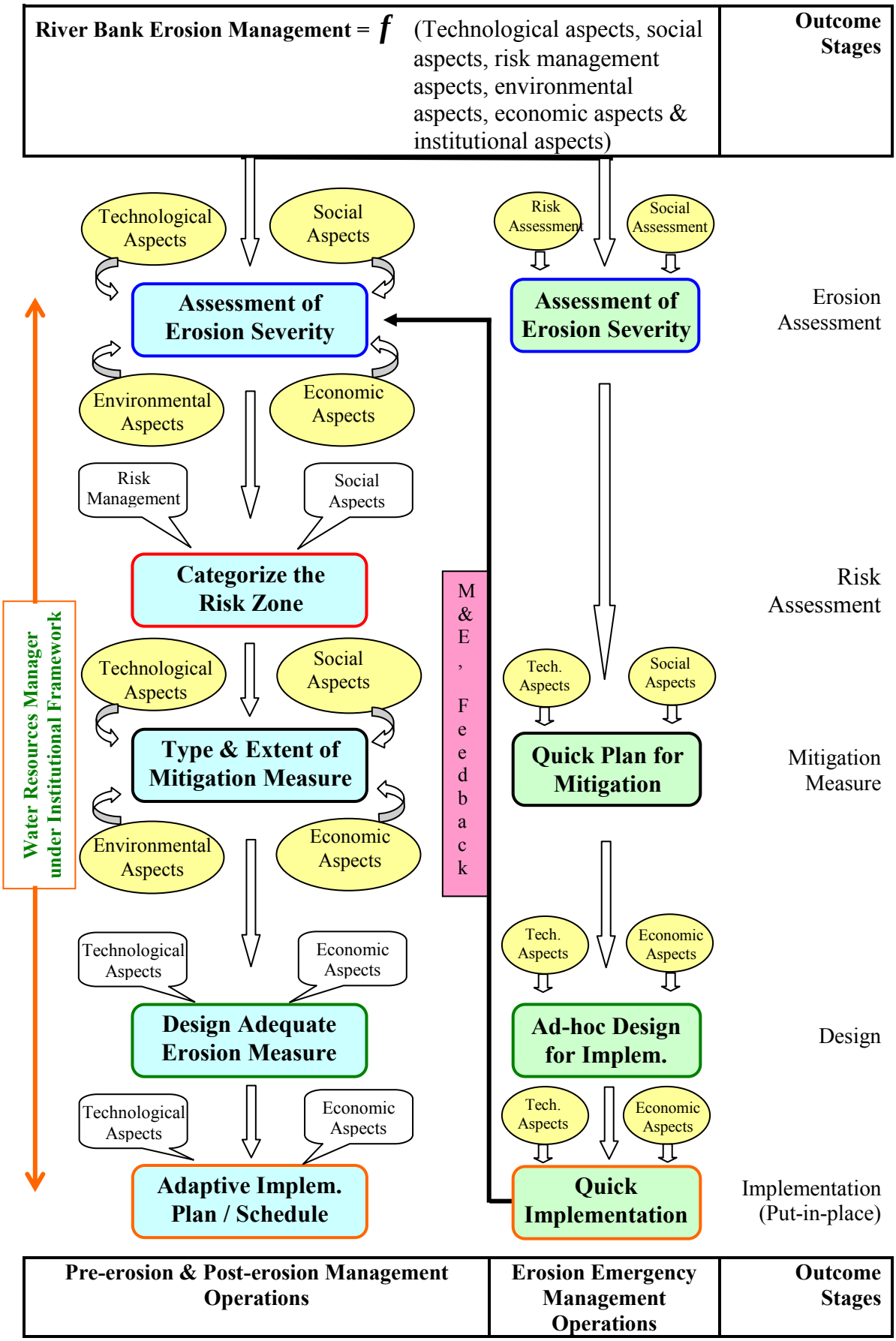
10.2 Integrated River Bank Erosion Management Framework

A new paradigm of integrated river bank erosion management framework (see **Figure 10.3**) has been developed addressing the functional relations of six individual aspects, i.e. technological, social, risk management, environmental, economic and institutional. The outcome stages follow the five steps: erosion assessment, risk assessment, mitigation measures, design and implementation. The functional component of each step has been formulated considering the end result of two or more aspects. Two separate management operations – (a) pre-erosion & post-erosion and (b) erosion emergency have been developed in this framework, where emergency work has integrated through monitoring and evaluation (M & E).

The water resources manager under an institution (for instance, Bangladesh Water Development Board, BWDB) can act as a planner/decision-maker to achieve targeted outputs following the implementation of mitigation measures. This framework illustrates the correlation between independent variables and dependent variables of each step. Generally, independent variables are specific inputs and dependent variables are result of individual aspects. At least two or more aspects has been integrated each other to achieve the indicator of each outcome stages.

Recurrent and extreme bank erosion creates several hazards with a negative impact on human lives, livelihoods and economy of a community. The proposed integration procedure in this framework for bank erosion management plays an important role. Moreover, it helps to select the suitable mitigation measures on the basis of risk-safety trade-off decisions. The IRBEM provides the rationality for taking decision because it provides some indicators on the scale of impact of individual aspects for feasibility. In order to minimize subjectivity in decision-making, sensitivity analysis and multi-criteria analysis plays a key role in trade-offs and conflict resolution.

Figure 10.3: Integrated River Bank Erosion Management Framework



CHAPTER ELEVEN

IMPLEMENTATION PROCEDURE AND APPLICATION OF IRBEM FRAMEWORK

11.1 Implementation Procedure of IRBEM Framework

The implementation procedures of IRBEM framework for selecting adaptive adequate erosion mitigation measures consider two types management operations: (a) pre-erosion and post-erosion and (b) erosion emergency. Both the cases there are five outcome stages: (i) erosion assessment, (ii) risk assessment, (iii) mitigation measures, (iv) design and (v) implementation. All outcome stages are supported by the dependent and independent variables/parameters of different IRBEM aspects. The data generation procedure for outputs of each outcome is briefly illustrated in the following section.

11.1.1 Erosion assessment procedure

The assessment of erosion severity is the main output of this stage. The relevant management aspects to generate the data for assessing erosion severity are technological aspects, social aspects, risk management aspects, environment and economic aspects. The key parameters of these aspects are given in **Table 11.1**.

Table 11.1: Key parameters for bank erosion assessment

Aspects	Parameters	Ranking
Technological	○ Actual extent of bank erosion ○ Morphological variables ○ Predicted extent of bank erosion ○ Magnitude of erosion hazard	Low /medium / high
Social	○ Socio-economic status ○ Gender ○ Employment ○ Land/property/infrastructure damage ○ Social dependence	Vulnerability index
Risk Management	○ Occupation ○ Source of livelihood ○ Environment degradation ○ Access to national power	Increase / decrease Increase / decrease Damage Knowledge
Environmental	○ Poverty & consumerism ○ Population growth	Migration Degradation
Economic	○ Physical damage	Actual pricing

Some of the above-mentioned parameters are interdependent on each other. The output of each aspect which links with the inputs of other aspects is illustrated in the respective chapters of each management aspects. At present erosion severity has been assessed on the basis of actual extent of bank erosion. In IRBEM a paradigm shift has been addressed to assess the erosion severity by integrating the all parameters suggested in Table 11.1. The interference of linked parameters needs to be judged to assess the total erosion severity instead of piecemeal severity. Emergency erosion severity can be assessed by analyzing the social and risk management parameters based on actual extent of bank erosion during the monsoon. Quick mitigation plan and ad-hoc design can be suggest by analyzing the parameters of technological and economic aspects. Quick mitigation can also be addressed to protect the important land, property or infrastructures which need the proper monitoring during the monsoon. For pre-erosion management operations, feedback by evaluating the quick implementation processes through learning by doing during post-erosion will supplement to assess the total erosion severity. The flowchart shown in **Figure 11.1** provides the erosion assessment procedure.

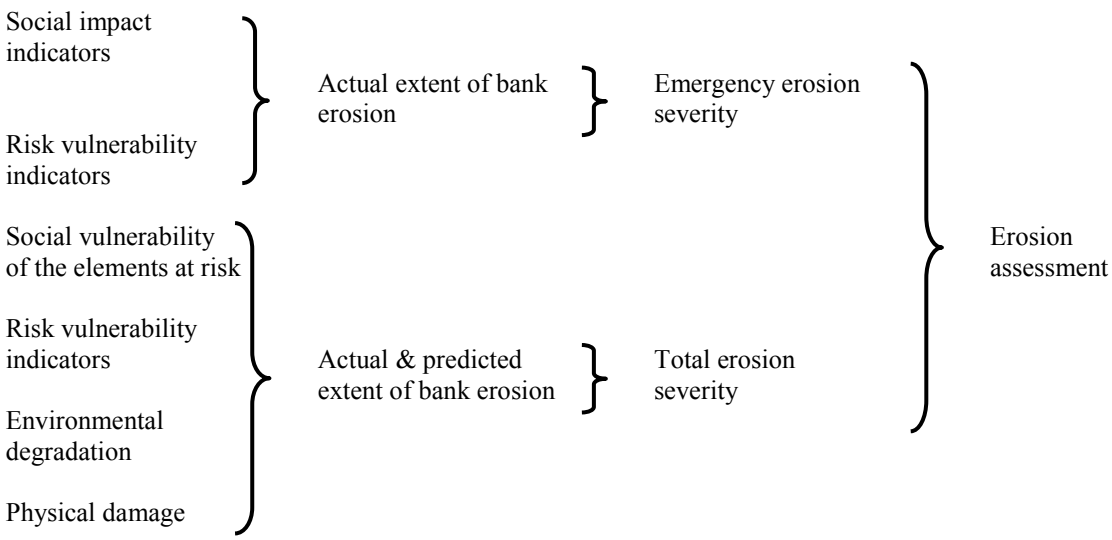


Figure 11.1: Erosion assessment procedure in IRBEM framework

11.1.2 Risk assessment procedure

The identification of risk zone is the main output of this stage. The identified risk zone may be categories as „high", „medium" & „low". The assessment of social factors and vulnerability conditions are two major components for risk identification. By analyzing

the social impact indicators on the basis of magnitude of erosion hazard social factors could be assessed. Detail of social factor assessment procedure is given in social management aspects (see chapter five). The vulnerability conditions could be assessed by analyzing the social vulnerability of the elements at risks and risk vulnerability indicators. The input-output processes including the systematic procedure for vulnerability condition assessment is given in social and risk management aspects (see chapter five & six). The flowchart shown in **Figure 11.2** provides the risk assessment procedure.

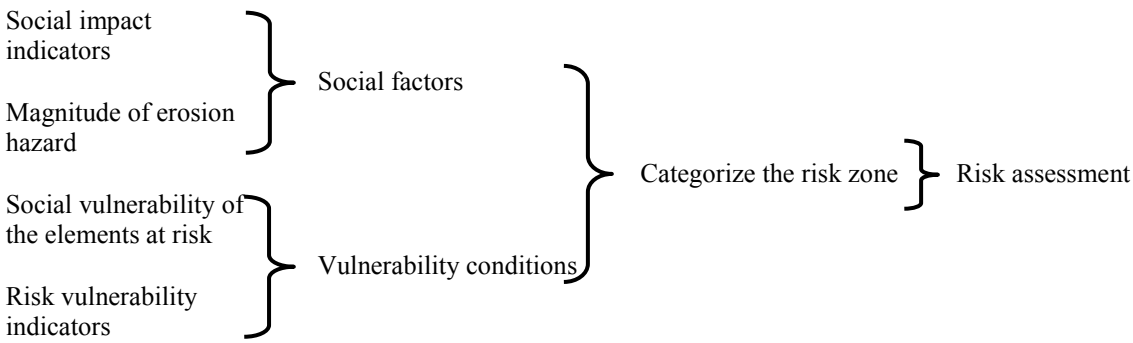


Figure 11.2: Risk assessment procedure in IRBEM framework

11.1.3 Mitigation measure procedure

There are two types of mitigation measure has been devised in IRBEM framework: (a) quick plan for protection and (b) suitable type & extent of mitigation measures. Quick plan for protection work is suggested for erosion emergency management operations. However, it is recommended to select the suitable type and extent of mitigation measure by analyzing the critical parameters of relevant management aspects. Quick plan for protection can be worked out on the basis of emergency erosion severity by assessing the social impact indicators and risk vulnerability indicators. In addition risk emergency management can be done through preparedness, response and recovery (details see in chapter six).

Land use regulations and its economic indicators are generally guided to select the type and extent of mitigation measure. Strategic environmental impact assessment can be carried out by regulating land use pattern and make plan for preparedness, response and recovery. Assessment of exposure cost and damage data lead to establish economic indicators. Assessment and evaluation of alternative options including the trade-offs

can be carried out through sensitivity analysis and multi-criteria analysis to select the suitable types and extent for mitigation measures. The flowchart shown in **Figure 11.3** provides the mitigation measure procedure.

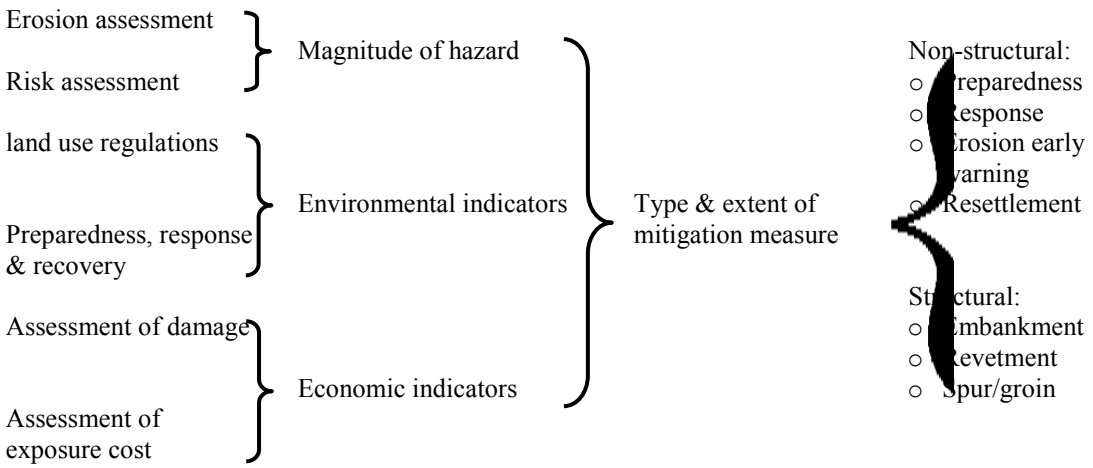


Figure 11.3: Mitigation measure procedure in IRBEM framework

11.1.4 Design procedure

The two major components, ad-hoc design and design of adequate erosion measure combine the design stage. Ad-hoc design is very much helpful for quick implementation during erosion emergency management operations. Hydraulic design variables/parameters, data generates from technological aspects, are the guiding factor to design any adequate erosion mitigation measure. Economic indicators, data generates from economic aspects, are the selecting criteria to make any trade-offs in between alternative mitigation measure. Combining these two features adequate erosion mitigation measure can be designed. The flowchart shown in **Figure 11.4** provides the design procedure.

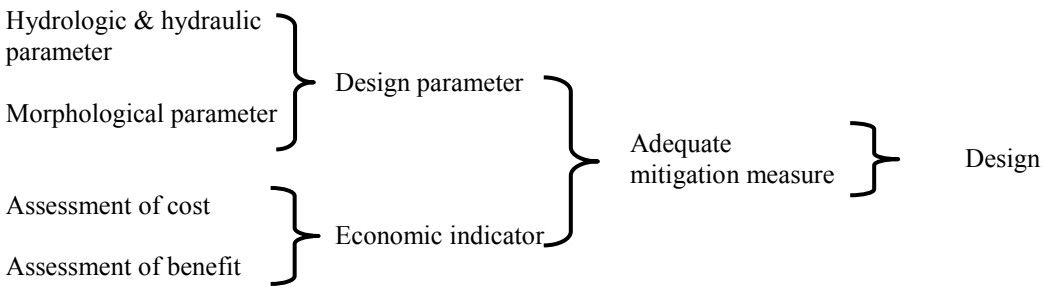


Figure 11.4: Design procedure in IRBEM framework

11.1.5 Implementation procedure

Adaptive implementation plan and quick implementation plan are the two components of implementation stage. Quick implementation can be done on the basis of ad-hoc design during erosion emergency management operations. For pre-erosion management operations, an implementation plan should be designed with "Adaptive Approach" covering execution timing, extent of protection work phasing, monitoring and evaluation phasing. A river bank erosion management policy is required under an institutional arrangement to implement the IRBEM framework where water resources manager can practice the five stages. The implementation procedure with its time horizon is illustrated in **Figure 11.5**.

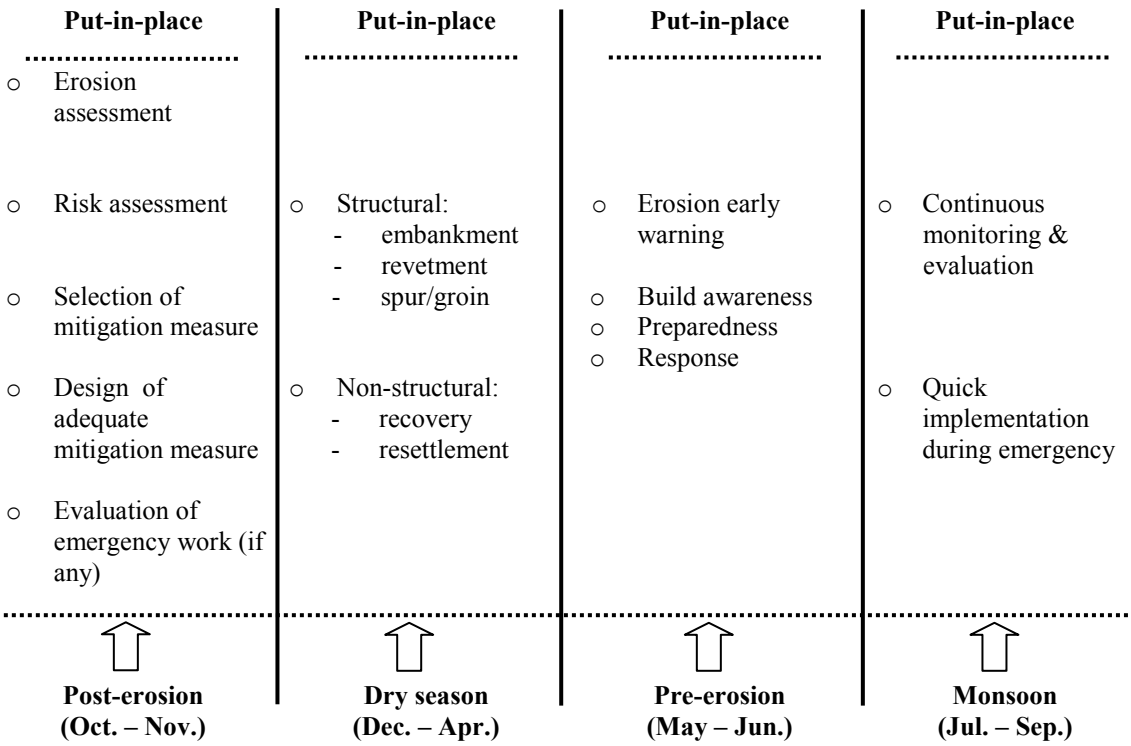


Figure 11.5: Implementation procedure in IRBEM framework

11.2 Application of IRBEM Framework

An application demonstration of the developed IRBEM framework for selecting adaptive adequate erosion mitigation measures and its implementation processes has been carried out on the basis of collected data and information. The selected erosion prone bank at ChanderChar along the Nabaganga River has been considered for this case study. In this connection, data and information has been collected through sample

surveys, questionnaire survey and focus group discussion (FGD) for social, risk, environmental, economic and institutional management aspects. In addition, primary and secondary data for technological aspects has also been collected. A spread sheet analysis for evaluating the responses of indicators of various aspects has been carried out for five outcome stages of IRBEM: (i) erosion assessment, (ii) risk assessment, (iii) mitigation measures, (iv) design and (v) implementation. All dependent and independent variables/parameters of each component of the outcome stages for ChanderChar erosion prone area has been determined and is briefly illustrated in the following section.

11.2.1 Erosion assessment

The assessment of erosion severity at ChanderChar has been evaluated through emergency erosion severity and total erosion severity. Emergency erosion severity has been assessed by analyzing the social impact indicators and risk vulnerability indicators based on actual extent of bank erosion during the monsoon. Total erosion severity has been assessed by analyzing the social vulnerability of the elements at risk, risk vulnerability indicators, environmental degradation and physical damage on actual and predicted extent of bank erosion. The erosion assessment procedure is also shown in flowchart (see Figure 11.1). All indicators have been assessed following an index with a scaling factor of category: low, medium and high. Scores for each indicator has been assigned and thus represent the performance of each indicator. Thereafter, a weighted average score is evaluated to judge the overall performance of a group of indicators ranging from low, low to medium and medium to high. The findings of bank erosion assessment are given in **Table 11.2** and the detail analysis is given in **Appendix-B**.

Table 11.2: Findings of bank erosion assessment at ChanderChar

a) Erosion Assessment	**medium to high**
i) Emergency erosion severity:	**medium to high**
Social Impact Indicators:	medium to high
Risk of Vulnerability Indicators:	low to medium
ii) Total erosion severity:	**low to medium**
Social Vulnerability of the Elements at Risk:	low to medium
Risk of Vulnerability Indicators:	low

	Environmental degradation constituents:	low to medium
	Physical damage:	medium to high

The scores of each indicator of social impact shows its category from low to high for erosion emergency severity (see **Figure 11.6**) based on actual extent of bank erosion. Accordingly, a comparison of impact on risk vulnerability indicators based on actual extent and actual & predicted extent of bank erosion is shown in **Figure 11.7**. The comparison shows that some of the indicator has significant reduced impacts while erosion warning sub-plan is executed through prediction of erosion extent.

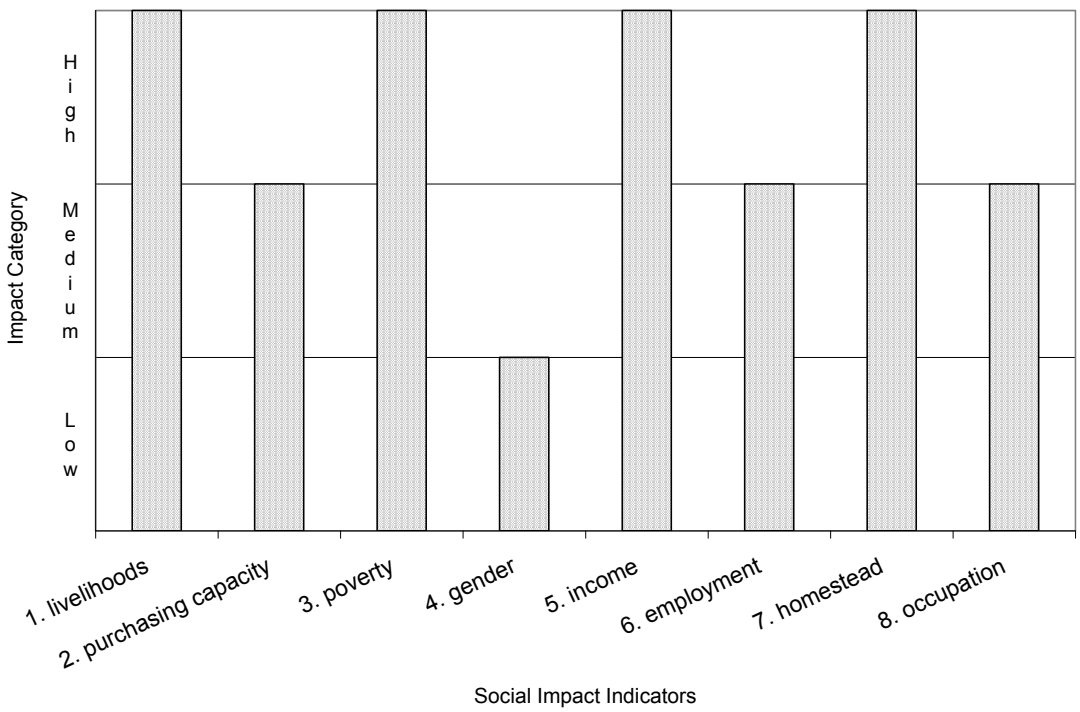


Figure 11.6: The scores of social impact indicators based on actual extent of bank erosion

11.2.2 Risk assessment

The bank erosion risk zone for ChanderChar has been identified by assessing the risk based on social factors and vulnerability conditions. The social impact indicators and magnitude of erosion hazard are combining to assess the social factors. The vulnerability conditions have been determined on the basis of social vulnerability of the elements at risk and risk of vulnerability indicators. The risk assessment procedure flowchart is also shown in Figure 11.2. Similar procedure of bank erosion assessment has been followed to evaluate the indicators of each component of risk assessment. The findings of risk assessment are specified in **Table 11.3** and details are given in

Appendix-B. The magnitude of impact of bank erosion hazard at ChanderChar is shown in **Figure 11.8**.

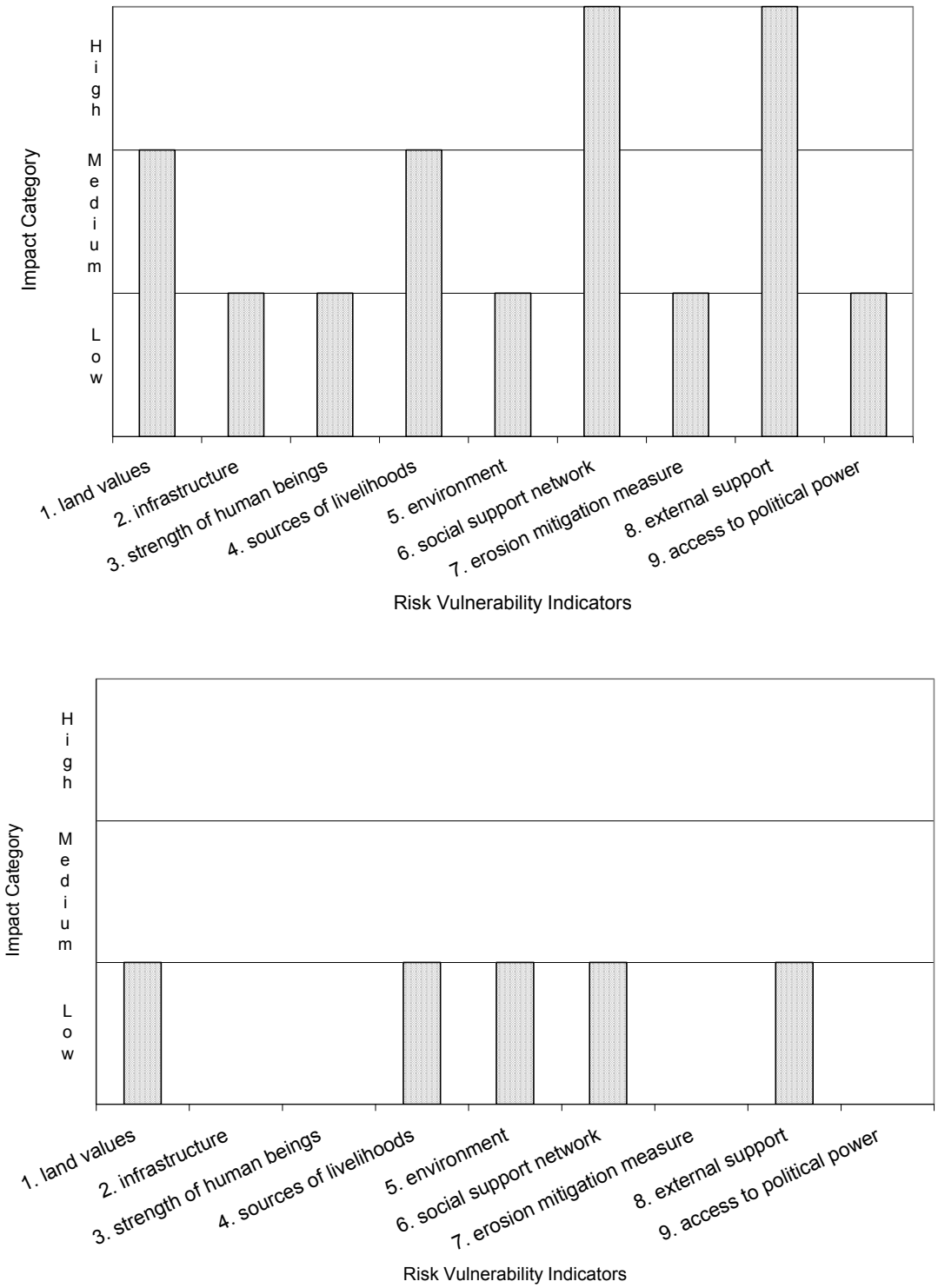


Figure 11.7: A comparison of impact on risk vulnerability indicators based on actual extent (top) and actual & predicted extent (bottom) of bank erosion

Table 11.3: Findings of bank erosion risk assessment at ChanderChar	
b) Risk Assessment	**medium to high**
i) Social Factors:	**medium to high**
Social Impact Indicators:	medium to high
Magnitude of Erosion Hazard:	low to medium
ii) Vulnerability Conditions:	**low to medium**
Social Vulnerability of the Elements at Risk:	low to medium
Risk of Vulnerability Indicators:	low

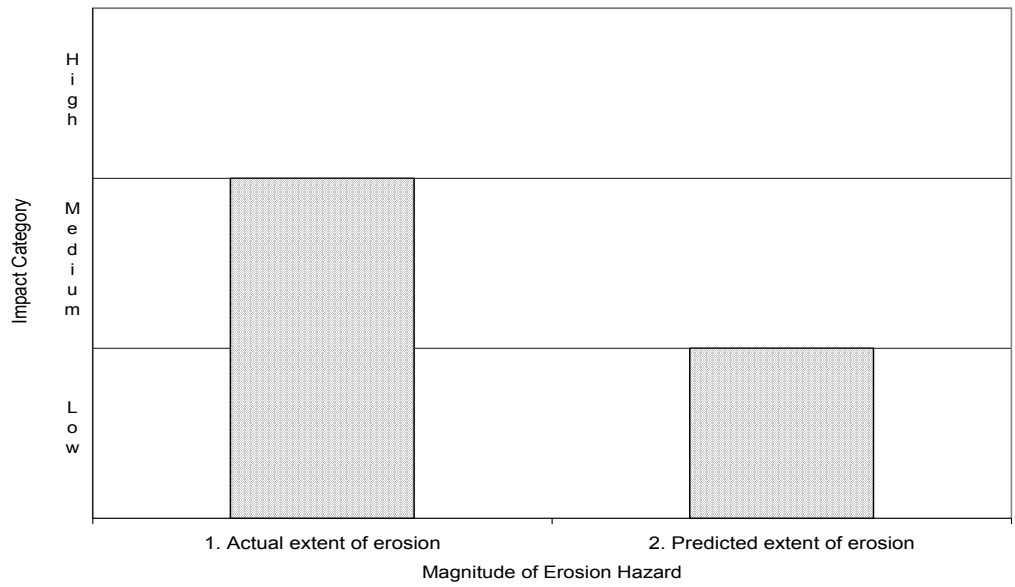


Figure 11.8: Impact depending on magnitude of bank erosion hazard at ChanderChar

11.2.3 Mitigation measure

The suitable type and extent of mitigation measures for ChanderChar bank erosion prone area has been selected following the criteria of magnitude of hazard, environmental indicators and economic indicators. The magnitude of bank erosion hazard depends on the findings of erosion assessment (see section 11.2.1) and risk assessment (see section 11.2.2). The land use regulations plan and preparedness, response & recovery processes are combining to assess the environmental indicators. The economic indicators depend on assessment of damage and assessments of exposure cost are playing a key role matching with other indicators to select the suitable type of mitigation measures. The mitigation measure procedure flowchart is also shown in

Figure 11.3. Similar procedure of bank erosion and risk assessment has been followed to evaluate the indicators of each component of mitigation measures. The following criteria (see **Table 11.4**) have been chosen to select the suitable type of mitigation measures including structural and non-structural interventions.

Table 11.4: Criteria for selecting suitable type of mitigation measures

Response of components			Suggested Type of Mitigation Measures	
Magnitude of hazard	Environmental indicators	Economic indicators	Structural	Non-structural
low	low	low		Awareness; Erosion early warning;
	low to medium	low		Erosion early warning; Preparedness;
low to medium	low	low to medium	Embankment	Awareness; Erosion early warning;
	low to medium	low to medium	Embankment	Erosion early warning; Preparedness;
medium to high	low	low to medium	Revetment	Awareness; Erosion early warning;
	low	medium to high	Revetment	Erosion early warning; Preparedness;
	low to medium	medium to high	Revetment	Erosion early warning; Preparedness; Recovery;

The findings for selection of suitable mitigation measures at ChanderChar for protection of bank erosion have been specified in **Table 11.5** and details are given in **Appendix-B**.

11.2.4 Design

The design of selected mitigation measure for structural interventions depends on hydraulic and morphological parameters. In this connection, only the required design parameters are listed in the **Table 11.6**. Accordingly, the data has been collected but the detail design has not been carried out. The assessment of benefits considering the past & predicted annual damage data of ChanderChar erosion prone area and the assessment

Table 11.5: Findings for selection of suitable mitigation measures at ChanderChar	
c) Type & Extent of Mitigation Measures	
Non-structural>>>> Structural>>>>	**erosion early warning & preparedness** **revetment + non-structural**
i) Magnitude of Hazard:	
Erosion Assessment: Risk Assessment:	medium to high medium to high
ii) Environmental Indicators:	
Land Use Regulations: Preparedness, Response & Recovery:	low low to medium
iii) Economic Indicators:	
Assessment of Damage: Assessment of Exposure Cost:	medium to high low to medium

of cost with multi-purpose use (bank protection, resettlement, agriculture) for demonstration has been carried out. The details of benefit and cost assessment is given in **Appendix-B**. The design of non-structural interventions could be carried out by analyzing the issues described in social, risk, environmental and economic management aspects. The design procedure flowchart is also shown in Figure 11.4. The implementation of the IRBEM framework needs the holistic approach as outlined in the institutional management aspects.

Table 11.6: Hydraulic and morphological design parameters	
d) Design	
	How to get data?
i) Hydrologic and Hydraulic Design Parameter	
Water Level Discharge Velocity	observed/simulated observed/simulated observed/simulated
ii) Morphological Parameters	
Plan-form Characteristics Shifting and Widening of the River Bend Characteristics and Cutoff Channel Cross-sections and Scour Depth	observed/calculated observed/calculated observed/calculated observed/simulated

11.2.5 Implementation

The detail implementation procedure for the developed IRBEM framework has been illustrated in section 11.1.5. In this research, IRBEM framework has been developed on the basis of collected data and information from two erosion prone sites at ChanderChar and Noagram along the Nabaganga River. In this chapter, a demonstration application procedure has been illustrated on the basis of ChanderChar data and information to evaluate the robustness of the developed IRBEM framework. The holistic implementation of the developed IRBEM framework needs the institutional commitments, assuring knowledge sharing concept including bottom-up and top-down approach.

11.3 Challenges in Operationalizing the IRBEM Framework

The challenges in operationalizing the developed IRBEM framework for erosion vulnerable bank are (i) assessment (actual and predicted) of bank erosion rate and its extent, (ii) collection of bank erosion damage data (actual and predicted), (iii) identification of the erosion vulnerable elements at risk, (iv) proper assessment of the social vulnerability index due to bank erosion, (v) collection of data and information ensuring participation of rightly identified stakeholders, (vi) judicious selection of the bank erosion risk assessment parameters, and (vii) implementation of bank erosion early warning sub-plan. In addition, integration of variables (parameters) of the six aspects needs to be sensibly reviewed for selecting suitable management plan of erosion vulnerable banks. These challenges can be overcome following the procedure developed in the schematic frame of individual aspects.

CHAPTER TWELVE

CONCLUSIONS AND RECOMMENDATIONS

12.1 Conclusions

In response to river bank erosion and its adverse impact on water resources management and sustainable development, a new paradigm of integrated river bank erosion management (IRBEM) framework has been developed. From times immemorial, near bank floodplains have been the preferred locations for human settlement, agricultural development, growth-centers and socio-economic development. It is because of their proximity to rivers, guaranteeing rich soils, abundant water supplies and means of water-way transport. Unfortunately, some of the river banks erode and cause considerable loss of lives, livelihoods, property, adverse impacts on the economy and people's safety. Therefore, living in the erosion vulnerable near bank floodplains is a challenge.

River bank erosion management involves the transformation of natural hydrological resources into a managed resource by minimizing the land and water impacts at the erosion vulnerable banks. In Bangladesh generally bank protection work are considered when the eroding channel seriously intrudes into areas where substantial economic development has taken place and hence significant damage might occur. Usually after severe bank erosion a project would be quickly planned, designed and implemented. The erosion problem and its solution seeming self-evident without giving any thought to the impact of such solutions that would have on upstream and downstream areas. Thus, present erosion protection practices have largely been focused on reducing erosion vulnerability through protecting the river bank only on structural solutions. Some of them could be complemented with non-structural measures, such as river bank erosion prediction and land use regulations.

However, any complete framework for river bank erosion management that could be practiced in Bangladesh is yet to be developed. Though some of the framework exists covering one or two aspects of river bank protection work has been practiced in a piecemeal way in Bangladesh. But the full benefits of the project by protecting the bank

never achieved. Sometimes structural measures has damaged partly or fully. Consequently, recognizing the importance of non-structural and structural measures, this research has been taken up to develop an integrated river bank erosion management framework, which addresses all relevant aspects of river bank erosion management. In this context, it is needed to be understood not only in the scientific and technological methodologies but also in institutional management and skills with community involvement covering techno-socio-economic aspects. The relevant aspects of IRBEM are technological management, social management, risk management, environmental management, economic management and institutional management.

Six individual schematic frames of each aspect considering all functional outcome stages have been developed based on their functional relationship between outputs of the particular aspect and inputs of other aspects. The important features of each schematic frame are illustrating below:

- The schematic frame of technological management aspects demonstrated a functional relationship in between prediction of river bank erosion rate for the tidal plain, risk identification approach, type of mitigation measures, design considerations and implementation plan.

- The schematic frame of social management aspects demonstrated a functional relationship in between prediction of river bank erosion rate for the tidal plain, livelihood security, poverty index linking to PRSP, resettlement plan. This frame also assesses the social perception on river bank erosion, social indicators influencing erosion vulnerability, identification of stakeholders and its response.

- The schematic frame of risk management aspects demonstrated a functional relationship in between prediction of river bank erosion rate for the tidal plain, risk perception on erosion hazard extent, social vulnerability index, and risk emergency management in-terms of preparedness, response and recovery.

- The schematic frame of environmental management aspects demonstrated a functional relationship in between prediction of river bank erosion rate for the tidal plain, ecosystem services and human well-being, drivers of environmental degradation, ecosystems and bank erosion processes, environmental indicators.

- The schematic frame of economic management aspects demonstrated a functional relationship in between prediction of river bank erosion rate for the tidal plain, assessment of benefits, assessment of cost, economic analysis, financial analysis, project design and implementation.

- The schematic frame of institutional management aspects demonstrated a functional relationship in between policy planning, defining law and implementation plan.

In addition, all schematic frames establish an interactive approach for pre-erosion and post-erosion management operations with erosion emergency management operations by introducing the monitoring and evaluation technique.

An integrated framework has been developed by linking common parameters of the six individual frames of different aspects through sensitivity analysis and multi-criteria analysis. Sensitivity analysis has been carried out by attempting three technological aspects, i.e. (a) actual extent of bank erosion, (b) predicted extent of bank erosion and (c) adopting exposure to determine the impact of actual outcome of a particular variable that was previously evaluated. The multi-criteria analysis follows two-stage procedure, i.e. (i) identify a set of goals and its trade-offs between the goals achieving a known strategy, (ii) identify "best" strategy by ranking weights (scores) to the various goals. It involves judging the expected performance of each erosion management aspects against a number of criteria. For example, (a) erosion zone may be classified as low erosion zone, medium erosion zone and high erosion zone, (b) human exposure may be classified as erosion prediction, preparedness, response, recovery, resettlement and structural measures, and (c) preference of mitigation measures may be classified as long-term preference (non-structural), short-term preference (structural & non-structural) and immediate preference (structural).

During the monsoon, continuous monitoring and evaluation in-terms of flow pattern, flow velocity, erosion and sedimentation processes is required to assess the erosion vulnerability. If needed quick implementation steps needs to be taken under an ad-hoc plan and design as an erosion emergency management operations. In this connection, the erosion emergency operations with respect to IRBEM aspects including its time horizon have also been developed. Warning needs to be provided in an understandable

manner following the local language through a legally designated single authority such as local erosion management association (LEMA).

The final IRBEM framework establishes five outcome stages: erosion assessment, risk assessment, mitigation measure, design and implementation. At least two or more aspects has been integrated together to achieve the indicator of each outcome stages. This framework illustrates the correlation between independent and dependent variables of each outcome stages. Generally, independent variables are specific outputs and dependent variables are result of individual aspects. In this framework, a procedure has also been developed for selecting the adaptive adequate erosion mitigation measures for two separate management operations: (a) pre-erosion & post-erosion and (b) erosion emergency has been addressed, where emergency work has integrated through monitoring and evaluation.

Finally, an implementation procedure of IRBEM framework has been developed for selecting the suitable adaptive erosion mitigation measures. The implementation plan designed with "Adaptive Approach" covering execution timing, extent of mitigation work phasing, monitoring and evaluation phasing. In order to minimize subjectivity in decision-making, the water resources manager under an institution can act as a planner /decision-maker to achieve the targeted outputs following the implementation procedure of IRBEM. IRBEM plays a key role to select the suitable mitigation measures on the basis of risk-safety, trade-off decisions and conflict resolutions. Moreover, the challenges in operationalizing the IRBEM framework have also been identified.

12.2 Recommendations

The conceptual framework of IRBEM has been developed on the basis of field data and stakeholder consultation. Field data from two erosion prone sites along the Nabaganga River has been collected. Several stakeholder consultation and FGD has been carried out to assess the individual component of six river bank erosion management aspects. In addition, consultation also made with designers/planners/decision-makers to establish a schematic frame for institutional aspects. Though the developed IRBEM

framework has its robustness and applicability, the following recommendations has been suggested for further study:

- This IRBEM framework could be implemented for river bank erosion management projects in any other locations of tidal plain;
- The developed concept of the individual frame of management aspects could be validated with new sets of data of other locations;
- The developed concept of this IRBEM framework could also be applied in the non-tidal plain.

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CHAPTER TWO

LITERATURE REVIEW

In Bangladesh, generally bank protection work are considered when the eroding channel seriously intrudes into areas where substantial economic development has taken place and hence significant damage might occur. The past experience of river bank protection has been varied with construction of embankments and ancillary structures dominating in the 1970s and 1980s. The devastating floods in 1987 and 1988 prompted the need for a more comprehensive strategy, which was initiated under several components of the Flood Action Plan (FAP). Several bank protection works were undertaken during the 1990s including for the protection of urban centers (i.e. Dhaka, Sirajganj, Chandpur) and for major infrastructure projects (i.e. Jamuna Multipurpose Bridge). The importance of non-structural measures was recognized during the FAP studies and this has now been embodied in Government strategy and reflected in the NWPo and NWMP. Therefore, the appropriate management strategy is necessary to formulate cost-effective sustainable approach for riverbank mitigation within a framework of structural and non-structural measures. In this connection, the following review of literatures has been carried out to assess the present status of bank erosion protection practices.

2.1 Previous Work on River Bank Erosion Management

- FAP 21 (2001) which was based on extensive experience with test structures in Kamarjani and Bahadurabad along the Jamuna River produced (i) a design manual for bank protection work and (ii) design methods for revetments including a proper upstream termination and permeable groynes;

- FAP 22 (2001) which gained some experiences with recurrent methods and closure of channels which in due time might be helpful while implementing a more offensive strategy such as construction of closure and construction of spur/groynes;

- Jamuna Multipurpose Bridge Project, where extensive experience was obtained in the construction of revetments and the closure of secondary channels;

- The construction of a number of RCC groynes along the Jamuna and Teesta Rivers, which have only been partly successful; however when properly analyzed the experiences gained can be used for improving design standards for groynes along the main rivers (Uddin, 2007); this type of groynes might be very useful for gradually narrowing the river;

- Jamuna Meghna River Erosion Mitigation Project (JMREMP), which since 2001 is exploring the use of geo-bags as bank protection materials in an adaptive approach with three structural options: (i) erosion mitigation option 1 – revetment, (ii) erosion mitigation option 2 – solid spur, and (iii) embankment retirement option. Recently, a new design manual was prepared for BWDB, including the adaptive approach using geo-bags (BRTC, 2008).

- Faridpur Town Protection need for proper bank erosion management strategy considering the developments in the Padma River near Faridpur. The southern anabranch was threatened Faridpur around 2005 and over the years anabranch has developed and moved. A structural option – revetment was exploring with adaptive approach to protect the eroded bank.

- Town Protection Project of BWDB implemented the piecemeal bank protection work along the regional major rivers which have only been partly successful;

- In China, the middle reach of the Yellow River was trained in the period of 1950 and 1990 by large-scale river training work.

2.1.1 Observations

The selection of management strategy for above projects is definitely only the technical issue. Over the last two decades quite a number of bank protection work have been implemented along all the major rivers of Bangladesh and some of them are damaged partly or fully. But unfortunately their combined impact has never been evaluated as the project has no complete framework. So, integrated river bank erosion management strategy is required to assess both positive and negative impacts of large-scale river training work. Moreover, no strategic bank erosion mitigation project in the tidal plain is yet to be developed. With this aim, review of literature has been covered following the context of IWRM to develop the functional management framework by assessing

the gaps and recent knowledge on various aspects. The available literature of IWRM, generally does not address the particular issues of river bank erosion aspects of water resources. As a result, there is clearly a need to develop understanding on dealing with various aspects of river bank erosion management.

2.2 The Context of IWRM

IWRM seeks to facilitate management of the water resources of a country in a comprehensive, integrated and equitable manner by coordinating a multiplicity of policies, institutions, issues and complexities (BCAS, 2007). This coordinated development can be achieved through proper integration of two basic systems, the natural system and the human system. IWRM has been recognized as the tool needed to bring about changes in water sector management and reform. But due to its multi-dimensional approach, the proper implementation of IWRM is difficult and therefore the capacity of the relevant professionals needs to be assessed, and enhanced periodically to take it forward.

Natural resource management, towards better integration (BCAS, 2003) addresses the key questions of integration of natural resources in Bangladesh, particularly its linkages to poverty reduction and sustainable livelihood issues. This study attempts to look into the needs and approaches of mainstreaming natural resource management into policies, institutions and processes.

APFM (2004) reported that integrated flood management (IFM) integrates land and water resources development in a river basin, within the context of IWRM, with a view to maximizing the efficient use of floodplains and minimizing loss of life. A participatory and transparent approach which includes a representative range of stakeholders in the decision making process is another key component of IFM.

APFM (2006) also reported that floods are a natural phenomenon and should not be considered a hindrance to economic development. Flood disasters result from the interaction between hydrologic events and environmental, social and economic processes. IFM aims to reduce flood risks through a judicious combination of measures dealing with the magnitude of the hazards and the community's exposure and vulnerability to it. A clear understanding of existing and potential flood risks is

necessary to establish proactive and preventive risk reduction measures, which make up the IFM approach. The nature of the IFM approach requires extensive coordination between various stakeholder groups. Information sharing and networking is essential in order to ensure the efficiency and soundness of the approach and to anticipate and manage conflicts and enhance cooperation across jurisdictions and sectors.

2.2.1 Observations

Integrated Flood Management (IFM) approach discusses individually its four aspects: social, environmental, economic and legal. It seems that no framework has yet been developed individually of these aspects. Moreover, no integrated flood management framework by combining all these aspects has yet been developed. However, a complete framework for integrated river bank erosion management has taken up to develop under this study. River bank erosion management integrates land and water resources development in a river reach with a view to maximizing the use of floodplains and minimizing the loss of land. A participatory and transparent approach is inevitable in the decision making process introducing the various aspects of river bank erosion management such as technological, social, risk, environment, economic and institutional.

2.3 Technological Aspects

The river bank erosion and the sedimentary features along the alluvial river are very dynamic, complex and chaotic in nature. The changing bank lines cause's great sufferings to the people living its course and on its chars. Predictions are needed on planform developments including migration and abandonment of channels, bank erosion and on detail morphological processes. Two approaches so far have been found possible for planform prediction: (i) numerical/analytical – based on a mathematical description of the morphological processes; and (ii) empirical – based on long years of observation and experience.

Numerical methods require a better understanding of the morphological dynamics and a focus on small-scale processes. Empirical methods are based on observed data (like remote sensing data or surveyed bathymetric data) and attempts to detect "rules" and "laws" which govern the behaviour of the river. These methods try to find empirical

relations between hydraulic parameters and morphological processes. This particular approach mainly focuses on the sedimentary features of the observed river planform.

The highly dynamic nature of the river in Bangladesh not only causes suffering to floodplain dwellers but national losses as well, by eroding cultivated lands, settlements, commercial centers and infrastructures. To minimize the sufferings and losses, engineering interventions in the river bank have become inevitable. Prior information with a lead time prediction on probable bank erosion and sedimentation is required for the planning, design, implementation /construction, operation and maintenance of such interventions. In this connection, a detailed review work on available prediction module relevant to the tidal plain has been carried out.

2.3.1 Sedimentary features as a tool for empirical prediction

In Bangladesh, Centre for Environment and Geographic Information System (CEGIS, 2002) introduces sedimentary features as a new prediction tool for river bank erosion. These sedimentary features are: contraction bars, sharpened bars, sand wings, sand tongues and bank-side bars and considered as indicators of morphological behaviour. The nomenclature of the above sedimentary features is mainly based on their shapes and locations (see **Figure 2.1**). Generally speaking, sedimentary features may vary from a few hundred meters to a few kilometers and from a few weeks to a few decades respectively.

CEGIS (2002) developed a hypothesis to explain the formation processes of the sedimentary features and their significance in morphological changes: "*The sedimentary features that are observed in the dry season satellite images and are formed during the recession of the floods or beginning of the dry season, resulting from recent floodplain, chars or sandbars erosion immediately upstream and/or at place. This erosion indicates that these channels have been morphologically active during the flood recession or dry season and would remain active in continuing the erosion at least for a part of the subsequent monsoon, which is indicative for the plan-form developments of the channels concerned*".

Comments based on limitations:

The present use of this empirical prediction relating to morphological changes of rivers is found mainly in selecting probable vulnerable locations in macro-level planning for bank erosion in non-tidal plain. This prediction technique is necessary to improve by integrating it with numerical predictions. Then only it could be effectively used to warn floodplain dwellers and formulation of successful mitigation plan.

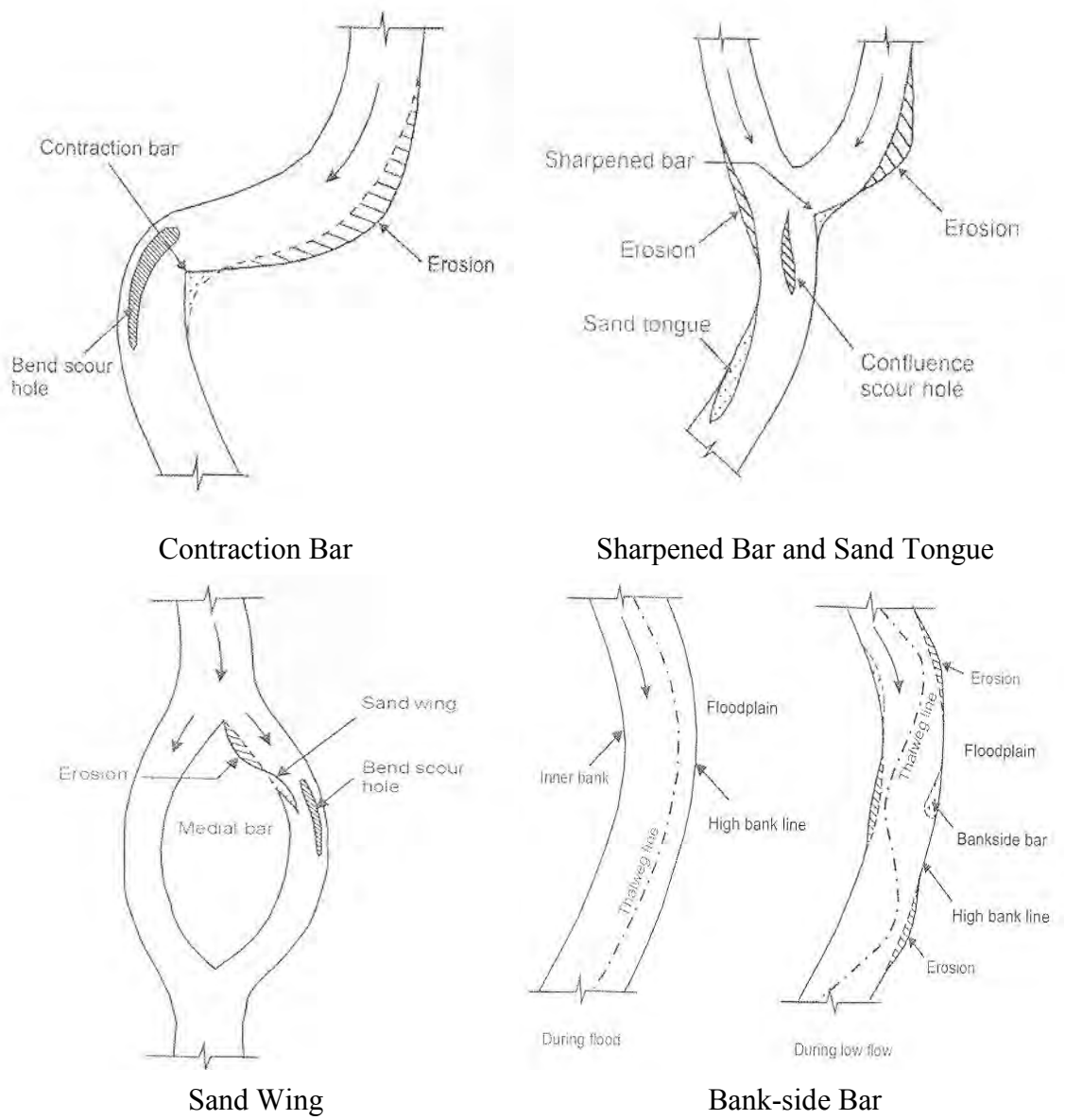


Figure 2.1: Schematic diagram, showing contraction bar, sharpened bar and sand tongue, sand wing and bank-side bar (Source: CEGIS)

2.3.2 Fluvial erosion and sedimentation features as a tool for numerical predictions

Numerical approaches, which contribute to a better understanding of the morphological dynamics, would enable the improvement of empirical relations. It should be noted that all available numerical tools rely on empirical relations. A two-dimensional (2D) mathematical model of MIKE21C (DHI, 2005) has been used by the Institute of Water Modelling (IWM) in Bangladesh. Moreover, the MIKE21C is a commercial package used in several countries. MIKE21C is a morphological modeling tool which is a combined hydrodynamic and sediment transport model. In this model, the hydrodynamic flow field is updated continuously according to the changes in bed bathymetry. The solution of hydrodynamics is solved at a certain time step prior to solution of the sediment transport equations. Subsequently, a new bed level is computed and the hydrodynamic model proceeds with the next time step. In this modeling system other sub-models such as bank erosion, bank line update, alluvial bed resistance, bed forms, and graded sediments are also included.

Following calculation of sediment transport of bed material (bed load and suspended load), the bed level change can be computed from the sediment continuity equation:

$$-a\frac{\delta z}{\delta t}+\frac{\delta S_x}{\delta x}+\frac{\delta S_y}{\delta y}=\Delta S_e \qquad (2.1)$$

where, S_x = Total sediment transport in x-direction;
S_y = Total sediment transport in y-direction;
a = Bed material porosity;
z = Local bed level;
t = Time;
(x, y) = Cartesian coordinate system; and
ΔS_e = Lateral sediment supply from bank erosion;

The sediment transport model includes bank erosion in the continuity equation:

$$E_r=-\alpha_1.\frac{\delta z}{\delta t}+\beta_1.\frac{S}{h}+\gamma_1 \qquad (2.2)$$

where, E_r = Bank erosion rate in m/s;
z = Local bed level;
S = Near bank sediment transport;
h = Local water depth; and
$\alpha_1, \beta_1, \gamma_1$ = Calibration coefficients specified in the model;

The extra sediment released when bank erosion occurs contributes to the sediment balance of Eq. (2.1). The contribution is obtained from the relation:

$$\Delta S_e = \frac{E_r . (\alpha + h_b)}{\Delta n} \qquad (2.3)$$

where, $h_b =$ Height of the bank above the water level;

$\Delta n =$ Width of cell next to bank line;

The near bank slope dependency, i.e., transverse bed slope at the bank is included by the α_1-coefficient. This is based on the assumption that the shape of the transverse bed profile is preserved. Therefore, from geometrical considerations the bank erosion rate is proportional to the bed erosion. Transverse bed slopes in natural rivers are typically of the order of 5-20 along eroding banks. This means that the α_1-coefficient should be chosen in the range from 0 to 20.

The dependency upon the near bank shear stress exerted from the river flow is implicitly included by the β_1-coefficient. This is based on the eroded material E_r, is moved downstream by the flow determined sediment transport rate *S*, or at least a fraction β_1 of it. This means that the β_1-coefficient should be chosen in the range from 0 to 1. Observed bank erosion rates are used to calibrate the coefficients α_1 and β_1. If no evidence for a relationship to $\frac{dz}{dt}$ or to *S* is found, then to specify a constant bank erosion rate γ_1.

Comments based on limitations:

- The bank erosion module assumes that the bank material is the same as the sediment on the river bed;
- The α_1-coefficient is based on the assumption that the shape of the transverse bed profile is preserved. The α_1-term stems from the link between scour and bank erosion. In sandy rivers it is often found that the transverse slope of an eroding bank remains constant when the bank line erodes. This means that the bank erosion and scour are directly proportional. The value of α_1 is theoretically the transverse slope ($1:\alpha_1$), but it should be calibrated for the particular application;

- The β_1-term expresses that a certain fraction (β_1) of the sediment transport capacity is used for transporting the material eroded from a bank;
- The γ_1-term is simply a constant bank erosion rate (m/s) used while the features are unknown;

The present use of this numerical model is very helpful to predict the probable vulnerable erosion prone area even in micro-level through calibrating α_1 and β_1 coefficient with observed bank erosion rate. This prediction technique needs to be incorporation of properties of bank soil characteristics, i.e., percent of silt-clay content (SC%). The critical shear stress (τ_c) for entrainment depends on eroding bank soil properties (after Vanoni, 1977) whereas in MIKE21C bed shear stress is defined as:

$$\tau = \frac{\rho g v^2}{C^2} \text{ , or in terms of Manning's M: } \tau = \frac{\rho g v^2}{\left(Mh^{\frac{1}{6}}\right)^2} \qquad (2.4)$$

2.3.3 Hydraulic erosion of cohesive riverbanks

The hydraulic erosion of cohesive riverbanks has been assessed by Julian and Torres (2005). They examined hydraulic bank erosion by separating estimated bank shear stress into four properties: magnitude, duration, event peak and variability. Stepwise regression between independent and dependent variables showed that the event peak of excess shear stress best predicts cohesive bank erosion with moderate critical shear stresses while the variability (all peaks) of excess shear stress best predicts erosion with low critical shear stress. These results suggest that the amount of hydraulic erosion of cohesive riverbanks is dictated by flow peak intensities. Finally, they produce a conceptual model for estimating bank erosion rates based on silt-clay content.

In attempts to understand the complex nature of cohesive riverbank erosion, some of the study findings are cohesive sediment is eroded through entrainment of aggregates (ASCE, 1968; Thorne, 1982). The detachment and subsequent entrainment of cohesive bank material can result from two processes: (i) hydraulic erosion – the lift and drag imposed by channel flow, or (ii) sub-aerial erosion – the weakening and weathering of

bank material imposed by dynamic soil moisture conditions (Thorne, 1982; ASCE, 1998).

The model most commonly used to predict hydraulic erosion rates of cohesive riverbanks (i.e., Osman and Thorne, 1988; Darby and Thorne, 1996) is

$$E_r = k(\tau_{bank} - \tau_c) \tag{2.5}$$

Where E_r is lateral erosion rate, k is an erodibility coefficient, τ_{bank} is applied bank shear stress by flow and τ_c is critical shear stress for entrainment.

The applied bank shear stress (τ_{bank}), in N/m^2, as calculated from the method of Flintham and Carling (1988) is

$$SF_{bank} = 1.77\left(\frac{P_{bed}}{P_{bank}} + 1.5\right)^{-1.4} \tag{2.6}$$

$$\tau_{bank} = \tau * SF_{bank}\left(\frac{B + P_{bed}}{2 * P_{bank}}\right) \tag{2.7}$$

Where SF_{bank} is the proportion of the total cross-sectional shear force acting on the bank, P_{bed} and P_{bank} are the wetted perimeters of the bed and banks respectively, B is the water surface width and τ is the cross-sectional shear stress.

The critical shear stress (τ_c) could be estimated by using silt-clay (<0.063mm) percentage (SC%) as a predictor (after Vanoni, 1977) combined with observations by Dunn (1959). By applying third-order polynomial trend line the generated rating curve:

$$\tau_c = 0.1 + 0.1779(SC\%) + 0.0028(SC\%)^2 - 2.34E-5(SC\%)^3 \tag{2.8}$$

The temporal distribution of excess shear stress (τ_{ex}) were calculated for all flow events by subtracting the τ_c values from the (τ_{bank}) values ($\tau_{ex} = \tau_{bank} - \tau_c$). Evaluating the τ_{ex} distributions on this flow event basis provided a bank erosion context in which the following properties were used as independent variables:

i. Magnitude (N/m^2), $\sum (\tau_{bank} - \tau_c)$

ii. Duration (min), time, $\sum (\tau_{bank} > \tau_c)$

iii. Event peak (N/m^2), $\sum (\tau_{bank} - \tau_c)_{max}$

iv. Variability (N/m^2), $\sum (\tau_{bank} - \tau_c)_{peaks}$

The values of these four τ_{ex} properties were assessed individually for each erosion measurement interval in order to determine the cumulative effect of each property on the measured erosion values.

Comments based on limitations:

- The assumption is made that the amount of hydraulic erosion is a function of the magnitude (i.e., total amount) of excess shear stress $(\tau_{bank} - \tau_c)$
- How τ_c varies with time and flow conditions has not been established (ASCE, 1998) and consequently was not incorporated into the rating curve or simulation;
- Transverse bed slope in the bank and helical flow intensity due to secondary current effect is ignored in this model;

2.3.4 Erodibility of cohesive streambeds

The erodibility of Cohesive Streambeds in the Loess Area of the Midwestern USA has been formulated by Hanson and Simon (1999). In this study, critical shear stress (τ_c) and erodibility coefficient (k) are used to define the erosion resistance of the streambed. Erosion resistance was observed to vary within a streambed, from streambed to streambed, and from region to region.

They assumed that the rate of erosion (E_r in m/s) is proportional to the shear stress in excess of a critical shear stress expressed as

$$E_r = k(\tau_{ex} - \tau_c) \tag{2.9}$$

where, k is the erodibility coefficient (m^3/N-s);
τ_c is the critical shear stress (Pa);
τ_{ex} is the effective excess shear stress (Pa);

The equation 2.9 indicates that the effective shear stress must be greater than the critical shear stress to initiate motion. An inverse relationship between τ_c and k was observed, where soils exhibiting a low τ_c have a high k and soils having a high τ_c tend to have a low k . The measure of material resistance to hydraulic stresses is a function of both τ_c and k . Based on their observations, k can be estimated as a function of τ_c .

$$k = 0.2\tau_c^{-0.5} \qquad (2.10)$$

Comments based on limitations:

- The authors did not define any relations for calculation of critical and effective shear stress for cohesive materials; and
- Whether erodibility coefficient would be used for calibration parameter or estimated value would be used as initial value for next simulation – not defined;

2.3.5 Generation of tension crack depth due to stream bank erosion

This study has been carried out by Langendoen and Simon (2008) and found that stream banks have been contributing as much as 80% of the total suspended load. The location, timing and magnitude of stream bank erosion are difficult to predict. Erosion of stream banks is a combination of: (i) lateral erosion of the bank toe by fluvial entrainment of in situ bank materials, often termed by hydraulic erosion; (ii) mass failure of the upper part of the bank due to gravity. The later erosion mechanism produces the greatest quantities of fine-grained sediments.

Some of the study findings reported as banks may fail by four distinct types of failure mechanisms (ACSE, 1998): (i) planar failures; (ii) rotational failures; (iii) cantilever failures; and (iv) piping and sapping failures. Steep banks commonly fail along the planar failure surfaces, with the failure block sliding downward and outward into the channel (Thorne, 1982). The stability of the bank is determined by the bank's geometry, bank stratigraphy, soil properties, pore-water pressures, confining pressure exerted by the water in the stream, and riparian vegetation. Simon et al. (2000) showed the importance of negative pore-pressures on stream bank stability. Positive pore-water pressures reduce the shear-strength of bank material to resist mass failure.

In this study, Langendoen and Simon estimate the tension crack depth (Y) as on Lambe and Whitman (1969) idea. This is usually equated to the depth at which the active pressure is zero.

$$Y = \frac{2c'}{\gamma} \tan\left(45^0 + \phi'/2\right) \qquad (2.11)$$

where, γ = bulk soil unit weight (kN/m^3);
c' = effective cohesion (Pa);
ϕ' = effective internal friction angle, deg;

Comments based on limitations:

- It is impractical to measure the soil properties along both banks of a stream at a very fine resolution.
- It is difficult to measure the actual values of c' and ϕ' as they occur in the field.
- Pore water pressure may also vary because of the variation in soil properties.

2.3.6 Fluvial erosion and mass wasting for cohesive river banks

This study has been carried out by Darby et al (2007) with a coupled simulation of fluvial erosion and mass wasting for cohesive river banks. They showed that the erosion of sediment from riverbanks is a key factor affecting a range of physical and ecological issues in the fluvial environment. Bank retreat often involves combination of fluvial erosion and mass wasting. These include the establishment of river and floodplain morphology and their associated habitats (Darby and Thorne, 1996).

2.3.7 Analytical approach for calculation of bank erosion

An analytical approach has been formulated by Duan (2005) for calculation of river bank erosion rates. In this study, for cohesive bank material experiencing planar bank failure, a deterministic approach was adopted for basal erosion analysis, whereas the probability of bank failure was included in the analysis of bank failure. Finally, a method for calculating the rate of bank erosion was derived that integrates both basal erosion and bank failure processes, and accounts for the effects of hydraulic force, bank geometry, bank material properties and probability of bank failure.

The concept is that bank surface erosion occurs when entrainment of sediment particles from the bank surface is greater than deposition. The fundamental mechanics of planar bank failure include basal erosion that occurs at the upper part of the bank. When the down-slope component of gravity becomes greater than the bank resistance, the upper bank will collapse (Thorne, 1982). Because the cohesive resistances of bank materials are different below and above the water surface, the overall bank resistance varies with the height of the water surface and thus changes with flow discharge.

A study by Simon et al. (2000) indicated that the resisting shear stress on the surface of a failure plane is reduced due to loss of negative pore water pressure that plays an important role in triggering bank failure. In this analysis, flooding is assumed to be the primary natural event that causes bank failure. Thus, the frequency of bank failure correlates to the frequency of flooding. Bank material above water surface is dry, and underneath is saturated. Basal erosion occurs at the under water portion of bank surface, and destabilize the upper bank material until a flood event causes the upper bank material collapses. A part of the failure bank material will remain at the toe of bank, and the other will be transport downstream immediately.

Comments based on limitations:

- In this method the effect of pore water pressure is neglected and assumes the angle of repose.
- The appropriate critical shear stress (τ_c) is calculated from the Shield's diagram due to the lack of an appropriate equation to calculate critical shear stress of cohesive banks;
- The author opined that no literature is available to address the development of tension crack with basal erosion but to establish this theory, information of tension crack of the bank material is important.

2.3.8 Channel migration processes

This study presents the application of a two-dimensional depth-averaged numerical model to simulate the lateral migration processes of a meandering reach in the West Jordan River in the state of Utah. The study has been done by Chen and Duan (2008). A new bank erosion model was developed and then integrated with a depth-averaged

two-dimensional hydrodynamic model. The rate of bank erosion is determined by bed degradation, lateral erosion and bank failure.

Mosselman (1998) and Darby et al. (2002) coupled physical-based bank erosion models with two-dimensional, depth-averaged models of flow and bed topography in movable computational grids. Darby et al. (2002) considered the deposition of failed bank material at the bank toe and its subsequent removal. Both Mosselman (1998) and Darby et al. (2002) calculated the rate of bank erosion where bank erosion was assumed to be proportional to excessive near-bank flow velocity. Mosselman (1998) excluded the bank-failure process when simulating experimental laboratory cases for meandering evolution.

In this study, the angle of repose for bank material at the lower bank surface was calculated by using an equation derived by Zhang et al. (1989). During extensive laboratory experiments various sized sediment ranging from 0.06 mm to 2.0 mm were used:

$$\phi = 32.5 + 1.27 * d_{50} \qquad (2.12)$$

where, $\phi =$ angle of repose in degree and d_{50} represents median grain size in mm.

Comments based on limitations:

- The bank erosion model developed in this study is less applicable for widening channels with bed aggradations. As bank failure was considered a consequence triggered by bed degradation and lateral erosion that destabilizes the bank surface.
- A generic bank erosion model including all these failure mechanism is not practically available currently.

2.3.9 Meander bend migration rates

This study was done by Richardson (2002) and describes a simple analytical model using output data from one-dimensional hydraulic models for assessing meander bend migration rates. The model is based on a conversion factor for one-dimensional (1D) shear stress and designed as a first approximation. Converted shear stresses are

translated to bank erosion volumes, which in turn related to meander bend migration rates, using bank geometry and an appropriate sediment transport law.

Erosion often occurs at the outer bank of the meander channel as a result of elevated velocities and increased shear stresses. The overall rate of bank erosion has been shown to be related to the capacity of the outer bank flow to entrain field bank material, at the same time as continuing the process of bank-toe erosion (Thorne 1982).

In stable meandering channels, as meander bends increase in amplitude and migrate downstream through time, outer bank erosion is generally matched by sediment deposition on the inner bank. This concept of "excess" outer bank shear stress attempts to account for the work done across the entire channel to transport the sediment load carried from upstream, and assumes that sediment movement in the reach is essentially transport limited. The subsequent erosion volume (E_v) is then translated to a bank erosion rate (E_r) by dividing the erosion volume by bank height (h) assumes that the slope of the outer bank remains constant through time, which is a reasonable assumption for a channel migrating across its floodplain in dynamic equilibrium (Osman and Thorne, 1988).

$$E_r = \frac{E_v}{h_b.b} \tag{2.13}$$

Where, E_r = erosion rate (m/s);

E_v = erosion volume (m^3/s);

h_b = bank height (m, above outer bank thalweg)

b = outer bank erosion width (m, assumed equal to bank height);

Any appropriate sediment transport equation can be used to derive daily bank erosion volumes for each daily flow conditions. Before application, erosion rate needs to be calibrated with the observed data.

Comments based on limitations:

- This relationship is useful to quantify as most hydraulic models widely in use are one-dimensional (1D) and as such do not take into account the affects of curvature.

- The model described above does not take into account varying processes of bank erosion and failure.

2.3.10 Observations

The use of empirical prediction relating to morphological changes of rivers is found mainly in selecting probable vulnerable locations in macro-level planning for bank erosion in non-tidal plain. This prediction technique could be improved by integrating with numerical predictions using MIKE21C module through calibrating α and β coefficient with observed bank erosion rate. Then it could be effectively used to warn floodplain dwellers and formulation of a successful mitigation plan. An analytical approach formulated by Duan (2005) for calculation of river bank erosion rates for cohesive bank and bed material is found to be suitable for prediction of tidal plain bank erosion rates. Three limitations were found in this approach: (i) ignoring the porosity with sediment escape velocity, (ii) assuming the depth of tension crack and (iii) angle of repose.

2.4 Social Aspects

Bank erosion along the river represents a considerable loss to the regional and national economy. Losses mainly consist of erosion of agricultural and urban land, damage to the property (houses, shops, public and private buildings etc.) and infrastructure (roads and bridges, power & telephone lines and railway tracks etc.). Urban centers, such as ports and towns which is trading and administrative unit are also under the threat of erosion. In addition to the above mentioned direct social and economic impacts, it is worth mentioning that the risk of erosion creates a significant constraint in the further development of public and private enterprises in the area.

2.4.1 Social aspects of risk reduction

APFM (2006b) reported that flood risks can be reduced by decreasing the magnitude of hazards, preventing exposure of people and their activities to flooding and diminishing vulnerability of flood-prone communities. Exposure to flooding can be generally reduced through:

- Structural flood mitigation works;
- Land-use planning and regulation;
- Flood emergency measures.

Structural measures include the construction of levees, floodwalls and bypass channels. These measures reduce the probability or degree of exposure to flooding. Structural measures such as flood-proofing, as their implementation require the active involvement of civil society. Land use regulations attempt to reduce exposure to flooding by keeping people away from flooded areas. People's exposure to impending floods can be prevented through flood emergency measures that involve moving them away from the flooded areas to avoid casualties caused by drowning or the spread of disease. Economic activities that are likely to be adversely affected by flooding can also be halted through early warning. The United States Federal Emergency Management Agency (FEMA) breaks flood-proofing down into five groups:

- *Relocation:* moving away from the flood-prone area;
- *Elevation:* raising the building above the flood level, either on piles or on a mound;
- *Floodwalls:* concrete or steel walls to keep the flood out;
- *Dry flood-proofing:* making the building water-tight;
- *Wet flood-proofing:* allowing basement and ground floor to flood while keeping habitable portions of the building above flood level.

Flood emergency management plans should form part of a comprehensive multi-hazard strategy towards risks in the region. Flood emergency management can be divided into three stages:

- *Preparedness:* pre-flood measures to ensure effective response;
- *Response:* measures to reduce adverse impacts during the flooding;
- *Recovery:* measures to assist the affected community to rebuild itself.

2.4.2 Stakeholder involvement in integrated management

APFM (2006b) also reported that flood management has largely been a top-driven, engineering-oriented process. In some countries public consultations have been carried out as part of a legal obligation with little or no participatory elements. Stakeholder

involvement in the decision-making process is perceived differently by different people and depends on the objectives of the process. Stakeholder involvement should be designed to include clear objectives, understanding of the pros and cons and an analysis of the stakeholders that need to be involved. The role of each stakeholder and the mechanism of their involvement have to be carefully designed so that they can be sustainable in the long-term.

IFM principles can be best adopted through participatory process which involves stakeholders in shaping, developing, identifying and implementing flood management strategies along with monitoring and evaluation during its implementation. The objectives of stakeholder participation in IFM are as follows:

- Provide all stakeholders, including the public, with full opportunities to share their views and influence the outcome;
- Build consensus and public support for the outcomes;
- Build stakeholders commitment;
- Ensure implementation of basin flood management plans with full public support;
- Ensure sustainability of plans and associated decisions;
- Build resilience of flood-prone communities.

Flood emergency planning is required at several levels: national, regional, district, upazila and community. Coordination is required among the following:

- Between government agencies, for example, disaster management committees at different levels and their member line departments, especially water resources management, public works, health, armed forces and police, economic and finance, planning, education, rural development, transport, communication, environmental and natural resources, where disaster management committees can take the lead and coordinate the planning process;
- Between the national, regional, district and local levels of these agencies, where a national disaster management body acts as the key facilitator for coordination during the planning stage and the respective district or community disaster management entities act as the key implementers of emergency measures;

- Among all emergency response agencies, such as government agencies, community flood management committees and other humanitarian NGOs, where national and local flood emergency management plans are shared with NGOs and vice versa.

The emergency preparedness plan is a detailed document containing sub-plans that address, among other things, preparedness for, response to and recovery from flood emergencies. Its primary aim is to clearly identify the responsibilities of various players during an actual flood. The risk assessment conducted at the local level in the form of flood hazard maps provides basic information on the likely extent of flooding, identifying flood-prone areas and the population residing in such areas. The plan should clearly spell out the responsibilities involved in disseminating flood forecasts and warnings, and identify the authority that will order and organize evacuations under various scenarios. Local authorities play the key role in flood emergency management with respect to flood warning, provision of labour and equipment, evacuation, management of safe havens and assessing and addressing relief camps needs. These functions need to be worked out during the development of the flood emergency plan (SCRAM, 2000).

2.4.3 Observations

Emergency management requires cooperation across sectors and administrative levels. In addition to resource mobilization, continuous, timely and precise information flow is vital for handling emergency situations. The development and implementation of flood emergency management strategies call for regular review and revision. Participatory planning is a prerequisite for emergency planning. At each level, all stakeholder groups concerned must come together to develop an emergency plan. Risk and vulnerability assessments, distribution of specific roles and responsibilities, resource analysis and mobilization are critical components of emergency planning which call for the participatory process. Results are then shared with all the stakeholders. Basin communities residing in flood-prone areas should be informed of the local risks to motivate them to take action to develop their own resilience. Lessons learned and good practices of one flood year need to be integrated into future plans. Similar experience can be shared to develop social aspects for bank erosion management.

2.5 Environment and Sustainable Management

APFM (2006a) in connection with environmental aspects reported that ecosystems provide enormous benefits to humans. Human security and well-being are closely related to maintaining ecosystems and avoiding environmental degradation. Human ingenuity is presented with a dilemma between development imperatives and environmental degradation.

The concept of "sustainable development" has been at the centre of the environment and development debate since the UN Conference on Human Environment in Stockholm in 1972 (UN, 1972). Sustainable development is: "the development that meets the needs of the present, without compromising the ability of future generations to meet their own needs" (UN, 1987). At the same time, "the right to development is an inalienable human right and an integral part of fundamental human freedoms" (UN, 1993). It is recognized that natural resources, the environment and development are interdependent (UN, 1992). Human development is closely related to and dependent on our natural surroundings and resources, including water, land, agriculture and forests. In developing countries, in particular, the livelihoods of millions of people depend directly on these natural resources, as there are often limited alternatives for economic growth and progress.

The environment can be defined as "the surroundings in which an entity operates. This includes air, water, land, natural resources, flora, fauna, humans and their interrelation" (PEER). The climate, the physical setting and the resulting river flow regimes, set within various ecosystems, with human activities superimposed, determine the environment of a flood plain. Human activities have profound impacts on the various ecosystems within the environment. An ecosystem is a dynamic system of plant, animal and microorganism communities and their nonliving environment, interacting as a functional unit (UN, 1992).

The Millennium Ecosystem Assessment describes ecosystem services as "the benefits that people obtain from ecosystems" (MEA, 2005). These include provisioning, regulating, and cultural services that directly affect people, and the supporting services needed to maintain other services. Many of these services are closely inter-linked. APFM (2006a) also reported that one of the main objectives of IFM is preservation of

environment. However, flood management policies are not designed in isolation. Being part of overall sustainable development, they have to be appropriately placed within the development matrix. It is, therefore, important to clearly understand the various drivers of development as well as environmental degradation. Moreover, ecosystems play a vital role in determining the hydrological response of a river basin.

2.5.1 Observations

It is necessary to understand the various hydrological processes generating floods, and how ecosystems interact with such processes to influence the volume, magnitude and timing of flood events. Similar features have to be specified to understand the important environmental components to develop environmental aspects of bank erosion management.

2.6 Economic Aspects as Decision Making Processes

APFM (2007) in connection with economic aspects reported that flood alleviation benefits are essentially for the public good, and, thus, flood management has to be carried out through a public policy framework. There are various constraints in any decision making process in flood management, which can be broadly categorized into: physical, financial, social, political, legal and environmental. Physical and financial considerations have largely been tackled through economic analysis with little or no attention to social and environmental concerns. These concerns are related to societal values, either regarding the perceptions of risks or the trade-offs between development and environmental preservation. In order to minimize the role of subjective factors there is need for an environmentally sensitive framework to be established within decision-making processes.

The purposes of economic analysis are both to simplify the complex to a level that we can comprehend and to gain an understanding of what the choice involves. The contribution of economic analysis to decision-making lies in providing a set of fairly reliable tools for an objective evaluation of the benefits and costs of specific flood management projects in monetary terms so as to enable their comparison and judge the economic viability of the proposed projects. Economic viability of projects is examined

with reference to the indicators, namely net present value (NPV), BC ratio or internal rate of return (IRR).

2.6.1 Observations

Economic viability of a project has to judge to evaluate the choices involved. Similar analysis is also required for economic aspects of river bank erosion management to assess and evaluate the options.

2.7 Legal and Institutional Requirement

APFM (2006) in connection with legal and institutional aspects reported that the law relating to IFM must clearly establish a framework that defines the rights and obligations of institutions and individuals at both the planning and operational phases of all stages of a flood event – before, during and after. At the same time it also needs to provide an equitable framework for development among different sectors of society, including present and future generations, to duly respect the principles of IFM and take account of the need to maintain the life support system provided by natural resources. This framework may address resource sharing, financial support and other practical measures. In addition to general developmental issues, a legal framework should provide for the following specific issues:

- Coordination and cooperation between the various organizations, institutions, sectors and users;
- Availability and accessibility of the basic data and information for informed decision-making;
- Building an enabling environment for all stakeholders to participate and make collective decisions.

Integrated Water Resources Management is now widely accepted to be the best way of ensuring that water resources management is administered in a sustainable manner (GWP, 2000). An integrated basin approach is recognized as a key requirement to reduce flood risk (EUC, 2004). This concept has been encapsulated in legislation in many countries, notably South Africa (SAWA, 1998) and Australia (QWA, 2000) and in the European Union Water Framework Directive (EC, 2000).

2.7.1 Observations

Legal and institutional arrangement is inevitable for application of IWRM concept in a sustainable manner. Similarly, a clear understanding on institutional aspects is very much essential for bank erosion management issues.

2.8 Synthesis of Knowledge Gap and Research Needs

The review of literature reveals that complete framework for river bank erosion management is not yet developed. Though some of the framework exists covering one or two aspects of river bank protection work has been practiced in a piecemeal way in Bangladesh. But the full benefits of the project by protecting the bank never achieved. Sometimes structural measures has damaged partly or fully. Consequently, recognizing the importance of non-structural and structural measures, this research has been taken up to develop an integrated river bank erosion management framework, which addresses all relevant aspects of river bank erosion management.

If bank erosion management is to be carried out within the context of IWRM, erosion management decisions must take into account not only their effect on erosion risk mitigation, but also of the resulting economic and environmental impacts. Accordingly, the planning and decision-making processes of a number of separate development authorities, whose decisions in any form influence the hydrological response of the erodible bank, must be coordinated to ensure that the common goal of sustainable development is achieved. In addition, decision-making processes for other development activities must take into account erosion risk because of their potential to affect the hydrological response of floodplains. At the same time, there should be some mechanism to ensure that local views and experiences are in turn communicated to national planning processes.

CHAPTER THREE

METHODOLGY

3.1 Approach and Methodology

The detail approach and methodology as research outline has been illustrated below to recommend a new paradigm of river bank erosion management framework following the procedure of techno-socio-economic-institutional aspects (see **Figure 3.1**) to achieve the targeted specific aims:

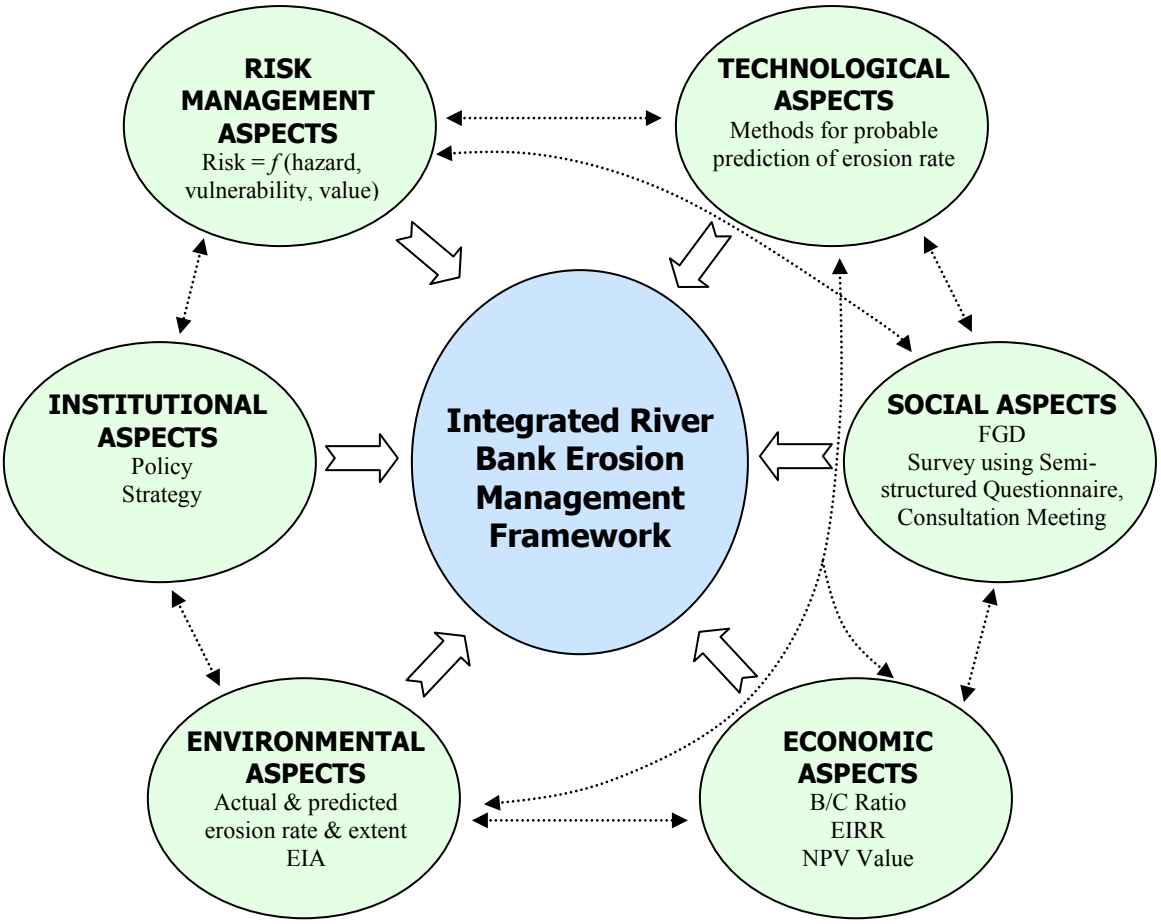


Figure 3.1: Procedure of Integrated River Bank Erosion Management (IRBEM) Framework with different Aspects

a. Technological Management Aspects:

Approach ➔ Conventionally, risk of river bank erosion is expressed in terms of extent and magnitude of erosion depending on the probability of a flood of a given

magnitude on a particular stretch of river. The morphological change pattern along the erosion vulnerable reaches during monsoon would necessary to be evaluated for extreme, medium and low hydrological event condition. The functional form of technological aspects depends on actual and predicted river bank erosion rate and evaluation of changed morphological pattern. Evaluation could be done through empirical approach or analytical approach or mathematical modeling or using satellite imagery or a combination of two.

Methodology ➔ The empirical approach has been followed to select the location of erosion vulnerable reach as macro-level planning using satellite imagery. Then analytical approach has been followed to select the extent & severity of probable bank erosion rate as micro-level planning using hydraulic characteristic data of the river and properties of bed/bank material. In this connection, due to non-availability of numerical model for a tidal plain, an analytical approach for prediction of river bank erosion rate has been established. Moreover, bank erosion features in the tidal plain has also been evaluated.

Finally, a schematic frame of technological management aspects has been developed to identify technologically sound mitigation measures by achieving the specific aims (i) & (iii).

b. Social Management Aspects:

Approach ➔ Both population and economic growth exert considerable pressure on the natural resources of a system which causes further increase of risk due to bank erosion. It needs to be ensured that the weaker sections of the population who largely occupy the near bank floodplains do not suffer further due to bank erosion or by the application of mitigation measures which reduces their livelihood opportunities.

The poor people along the river side have to cope not only with socio-economic realities (such as population dislocation, programs of economic reforms, and poverty etc.), but also environmental degradation and extreme weather events (such as floods, climate change). The poor people become unable to cope with extreme river bank erosion events. This vicious cycle would only stop when adequate mitigation measures are taken and preparedness systems are put in place in right

time. There is a clear need to initiate dialogue towards linking the contents of the Poverty Reduction Strategy Paper (PRSP) with the proposed IRBEM context, as dependence between poverty, livelihood and natural resources are closely linked.

Population growth and the migration of large populations towards unplanned urban and rural settlements in floodplains increase the vulnerability of the poorest sectors of society due to bank erosion. So, a resettlement plan is needed to find out an effective solution for displaced people and to be effective resettlement require active participation of the communities right from the planning stage.

It is seen from various field condition that mitigation methodologies developed on the basis of technical studies alone or without studies have very little chance of success, unless they have been drawn up in consultation with the stakeholders" right from the beginning. The functional form of social aspects depends on prediction of river bank erosion rate, livelihood security, poverty index linking to PRSP and resettlement plan.

Methodology ➔ A social survey using focus group discussion (FGD) and semi-structured questionnaire has been carried out to collect the qualitative information on erosion, damages, house-hold, agriculture, occupation, education, health and resettlement of affected people. All the collected data have been analyzed qualitatively to assess the socio-economic impacts, social factors to determine the community vulnerability. A participatory mechanism has been developed to assess the hazard relating with vulnerability of the elements at risks for devising early erosion warning sub-plan, evacuation sub-plan, recovery sub-plan and resettlement plan.

Finally, a schematic frame of social management aspects has been developed to identify socially acceptable mitigation measures by achieving the specific aims (ii) & (iii).

c. Risk Management Aspects:

Approach ➔ Modern society is termed a "risk society". Uncertainty and risk management are recognized that "risk" is a social construct resulting from the

accumulated or short-term effects of social and economic processes. Thus, risk management is a necessary component of river bank erosion process.

The mitigation measures to be adopted for protection of river bank erosion could be categorized based on “low”, “medium” and “high” risk. The continuous monitoring regarding the bank line migration and changed morphological processes along the river would be required for the selected eroded vulnerable reach to be brought under management plan. Accordingly, in the decision making processes the whole management plan would be evaluated to take the appropriate mitigation measure.

The functional form of risk management aspects depends on actual and predicted river bank erosion rate, magnitude of hazard extent, social vulnerability index and economic loss.

Methodology ➔ The risk assessment procedure has been developed based on functional value of risk, vulnerability of the elements at risk through hazard assessment. The risk perception module has also been developed by reducing exposure and enhancing resilience of the society.

Finally, a schematic frame of risk management aspects has been developed to identify risk free mitigation measures by achieving the specific aims (ii) & (iii).

d. Environmental Management Aspects:

Approach ➔ Some structural bank erosion mitigation interventions (spur/groyne) adversely impact riverine ecosystem by deflecting the river flow from the bank or changing the river course and owe the large variety of flora and fauna to this phenomenon. Now, question remains - What is desirable to reduce extreme bank erosion? Thus a tradeoff between competing interests in protecting the river bank is required by estimating the reach to be protected through minimizing the benefits to society and maintain a healthy riverine ecosystem.

Flood forecasting and warnings are obvious examples of a variability based approach: the problem is to predict what will happen in the future in a certain place. The probability of river bank erosion also depends on the magnitude and duration of floods. Therefore, river bank erosion prediction and warnings are apparent

instances of climate variability and change. The functional form of environmental aspects depends on prediction of river bank erosion rate, initial environmental examination (IEE), and environmental indicators.

Methodology ➔ An environmental impact assessment procedure has been developed based on environmental indicators sensitive to river bank erosion through initial environmental examination.

Finally, a schematic frame of environmental management aspects has been developed to identify eco-friendly mitigation measures by achieving the specific aims (i) & (iii).

e. Economic Management Aspects:

Approach ➔ A number of datasets (cropland, houses, homestead, trees, tube-well, shops, markets, roads, school, health centers etc.) which could be saved by protecting the river banks is required to carry out the economic analysis.

Living on floodplains involves risk, and for this there is a price to pay. The cost of living on floodplains is borne by floodplain occupiers, by way of economic losses and reduced opportunities. To what extent this split is acceptable depends on the social and economic construct of the society. To what extent a government should fund river bank erosion mitigation activities and will largely depend on the socio-economic policies of the government. The functional form of economic aspects depends on actual and predicted river bank erosion rate, resources/assets to be saved, and appropriate economic instrument.

Methodology ➔ The procedure of economic analysis has been developed through assessing the assets to be saved following economic instrument of B/C ratio, EIRR and NPV.

Finally, a schematic frame of economic management aspects has been developed to identify economically viable mitigation measures by achieving the specific aims (iii).

f. Institutional Management Aspects:

Approach ➔ Stakeholders with different sector, region and local perspective have different institutional and cultural backgrounds and socio-economic conditions, which call for different capacity-building approaches depending on their respective roles, and their orbit of influence. A policy and strategies needs to be developed making relevance with NWMP and national water policy (NWPo). The strategies developed for IRBEM need to be translated into specific policies for planning, allocation and management of resources.

The establishment of legal mechanisms for more effective community representation is imperative. This requires an enabling institutional framework, which facilitates rather than hinders effective coordination, cooperation and collaboration across jurisdictional boundaries, departments, institutions, disciplines, users and uses. Accordingly, an institutional framework would be delineated by accommodating learning by doing/experiencing.

The requirement for stakeholder involvement needs institutions that are community based. The functional form of institutional aspects depends on the legal framework, institutional roles and responsibility, institutional capacity and stakeholder involvement from outset of planning and development.

Methodology ➔ The institutional roles and responsibilities have been defined and fix the IRBEM strategy in connection with bank protection measures by delineating legal framework through institutional capacity building.

Finally, a schematic frame of institutional management aspects has been developed to identify institutionally acceptable mitigation measures by achieving the specific aims (i), (ii) & (iii).

After developing the six individual frames of different aspects, an integrated framework has been developed building the linked parameters to address the techno-socio-economic impacts on river bank erosion management using multi-criteria analysis (MCA) and measuring sensitivity of parameters. At the end implementation and application procedure of IRBEM framework has also been developed.

3.2 Data Collection Procedure

a. Socio-economic survey data:
(for Social, Risk, Environmental and Economic aspects)

Sample surveys
A sample survey has been applied to an erosion victim people at ChanderChar and Noagram village along the bank of the Nabaganga River. The sample size has been determined based on the erosion affected people households/individuals. In this regard Union Parishad (UP) personnel‟s has also been interviewed. The sample surveys has been on multiple subjects, such as social, risk, environment and economic aspects. The data has been collected:

- through filling up a questionnaire;
- through interviews;
- through observation of respondents or the phenomenon under study; and/or
- through some combination of these procedures.

A sample survey is a flexible method and suits the requirements of data to achieve the targets where inferences have been drawn (Mukharjee, 2003). In this connection, number of erosion affected households at ChanderChar and Noagram has been interviewed and based on that sample size has been fixed by taking approximately 10% of the total households to ensure the representative samples.

However, a statistical significant sample size, which represents the entire target population, has also been assessed with the following equation (BWDB, 2004):

$$n = \frac{Z^2 pq}{e^2} \tag{3.1}$$

where, n = the desired sample size
Z = the standard normal deviate
p = the portion in the target population estimated to have a particular characteristics
q = 1.0 – p
e = degree of error desired

The Questionnaire survey

The most widely used method for collecting socio-economic data is that of questionnaire survey which entails administering a written questionnaire to respondents (Mukherjee, 2003). This type of survey had been done at one point of time through interviews of individuals and collected data has been validated through focus group discussion (FGD). In this regard, participatory rural appraisal (PRA) method has been used. The questionnaire has been defined as a group of questions designed to elicit information upon the subject mentioned, or a sequence of subjects, from a set of respondents. A standardized questionnaire survey generally reflects the product of survey is usually qualitative, sometimes quantitative or numerical figures describing the characteristics of above mentioned subjects. The collected data has been analyzed are the answers given by the respondents.

Participatory Rural Appraisal

The participatory rural appraisal (PRA) is a methodology which helps in interacting with local communities, understanding them and learning from them (Mukherjee, 2003). It helps in the process of involvement with local communities like erosion victim people for indigenous knowledge-building exercises. It is way of learning from and with community members to investigate, analyze and evaluate constraints and opportunities and make informed and timely decisions regarding development projects. It provides an alternative framework for data collection and analysis because of its participatory nature. It is a useful methodology to focus attention on erosion affected people, their livelihoods and their inter relationships with socio-economic and ecological factors.

Focus Group Discussion

The six focus group discussions (FGD) have been carried out considering the homogeneous group of erosion affected people like farmers, fishermen, small businessmen and landless (displaced) people including the gender aspects.

b. Survey data for institutional aspects:

A sample survey has been applied to the decision-makers of BWDB and the sample size has been determined based on working professionals of planning, design and hydrology. The persons concerned bank erosion protection has been interviewed. The relevant persons of WaRPO, IWM & CEGIS have been interviewed. In this regard, no

FGD is possible. The inference has been drawn from the collected data information through interviews.

c. Primary and secondary data for Technological aspects:

Primary data:

- Water level & discharge data for 2008 monsoon condition at ChanderChar and Noagram erosion prone area of the Nabaganga River;
- River cross-sections at different time-frame of 2008 monsoon at ChanderChar and Noagram erosion prone area of the Nabaganga River;
- Bank line of erosion prone area at ChanderChar and Noagram;

Note: These data have been collected from the ongoing project of BWDB entitled "South West Area Integrated Water Resources Planning & Management: Bangladesh".

Secondary data:

- Historical water level & discharge data at Bardia on the Nabaganga River;
- 1D model generated data to compare the water level, discharge & velocity data at ChanderChar and Noagram erosion prone area of the Nabaganga River;
- Historical satellite imagery of the Nabaganga River;
- Grain size of river bed materials and bank materials of the Nabaganga River;

Note: These data have been collected from IWM and SPARSSO.

3.3 Data Analysis Techniques

The socio-economic and institutional survey data has been analyzed qualitatively. Qualitative analysis deals primarily in words, and rest on the ability to systematically identify and interpret meaningful patterns of response and interrelationships in what is said by and/ or observed by the researchers. The collected data has been examined by determining how the stakeholder responded to the research questions. The data has been structured following two strategies for creating meaningful categories: (i) the direct interpretation of the individual instance and (ii) through categorical aggregation.

The direct interpretation of the individual instance has put-in-place through "data display". A data display is an extended piece of text – which is embodied separately in

the relevant article. The other forms of data display such as diagrams, tables, charts, or matrices have also been provided to present and think about data. This technique has been used as the analysis component of transforming qualitative data.

The categorical aggregation is employed to construct meaningful categories of the class of individual instances. This involves deciding what the data mean – what their implications are for the questions of research and simultaneously going back into the data to cross-check. It follows two-stage procedure: (i) identify a set of indicators and its index achieving a known strategy, (ii) identify "best" strategy ranking weights (scores) to the various criteria of each indicator. It involves judging the performance of indicators against a number of criteria. In this research, weights are assigned to each criterion and a scale of 1 to 3 is adopted. Thereafter, a weighted average score is evaluated. The idea generated for these indicators has been standardized following the protocol of investigator triangulation (expert"s opinion).

The primary and secondary data collected for technological aspects has been analyzed to predict the river bank erosion rate through analytical approach.

3.4 The Study Area

3.4.1 The Socio-economic features

The study area focuses on an area of Rajbari, Faridpur, Gopalganj and Narail district under south-west region of Bangladesh (see **Figure 3.2**). In the study area, there are two sub-projects namely Narail Sub-Project and Chenchuri Sub-project. About 56.4% of the households in Narail Sub-Project area were found to be functionally landless (having total cultivable land up to 50 decimal was considered to be landless), while the same in the Chenchuri Sub-Project area was 62.2% (BWDB, 2004). The Nabaganga River, which is Peripheral River of these two sub-projects, has been selected for case study of this research. The two erosion vulnerable locations i.e., ChanderChar and Noagram along the bank of the Nabaganga River (see **Figure 3.3**) have taken up to collect the primary and secondary data sets.

Major observations depicting from the two erosion vulnerable areas is detailed below:

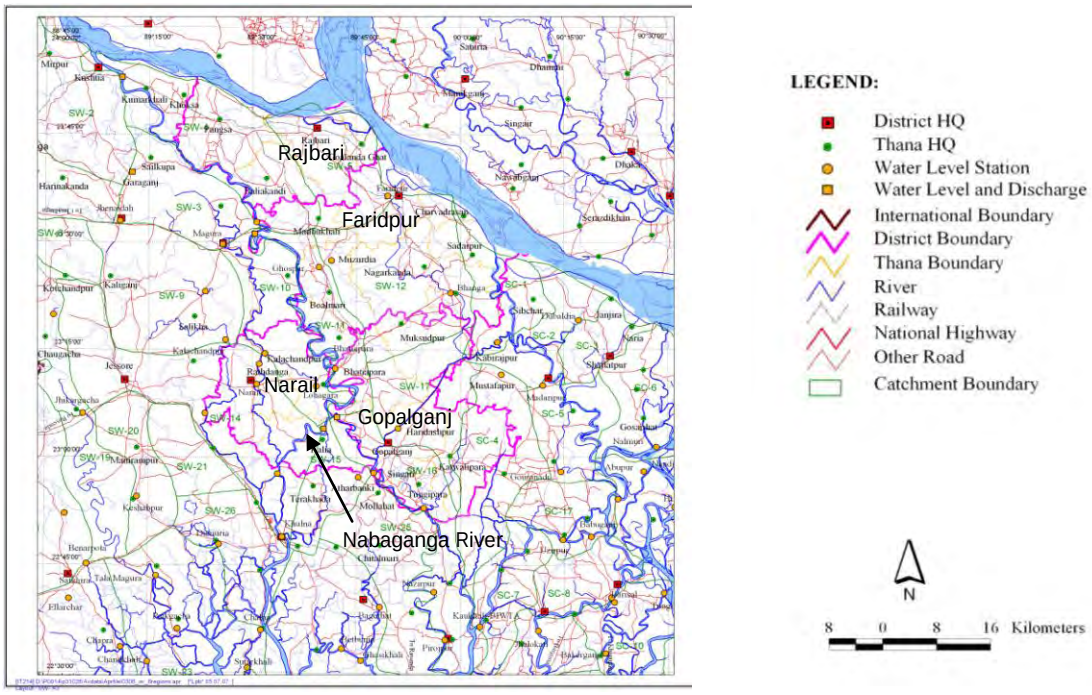


Figure 3.2: The study area covering Rajbari, Faridpur, Gopalganj & Narail district of Bangladesh (Source: IWM)

- In both areas maximum people engaged in major livelihoods are of agriculture, agriculture and non-agriculture day labouring, rickshaw/van pulling, small business.
- Quite a significant percentage of households especially females are engaged in livestock (goat and poultry etc.).
- It is also observed that households access to different GoB services and information is limited. NGO services were found to be very limited.
- Most of the erosion affected households are suffering from access to safe drinking water and they are living along the road side or embankment side. Significant percentage of the landless people used to migrate nearby city, capital city or Mumbai, India for searching alternative job.
- Poverty encompasses all types of human deprivation including income, nutrition, health care, education and employment.
- It is suggested by the community to rehabilitate them in the Government owned „Khasland", immediate needs for appropriate bank erosion protection measures, training on income generating skills with financial support (especially for women), awareness with early erosion warning and prediction etc.

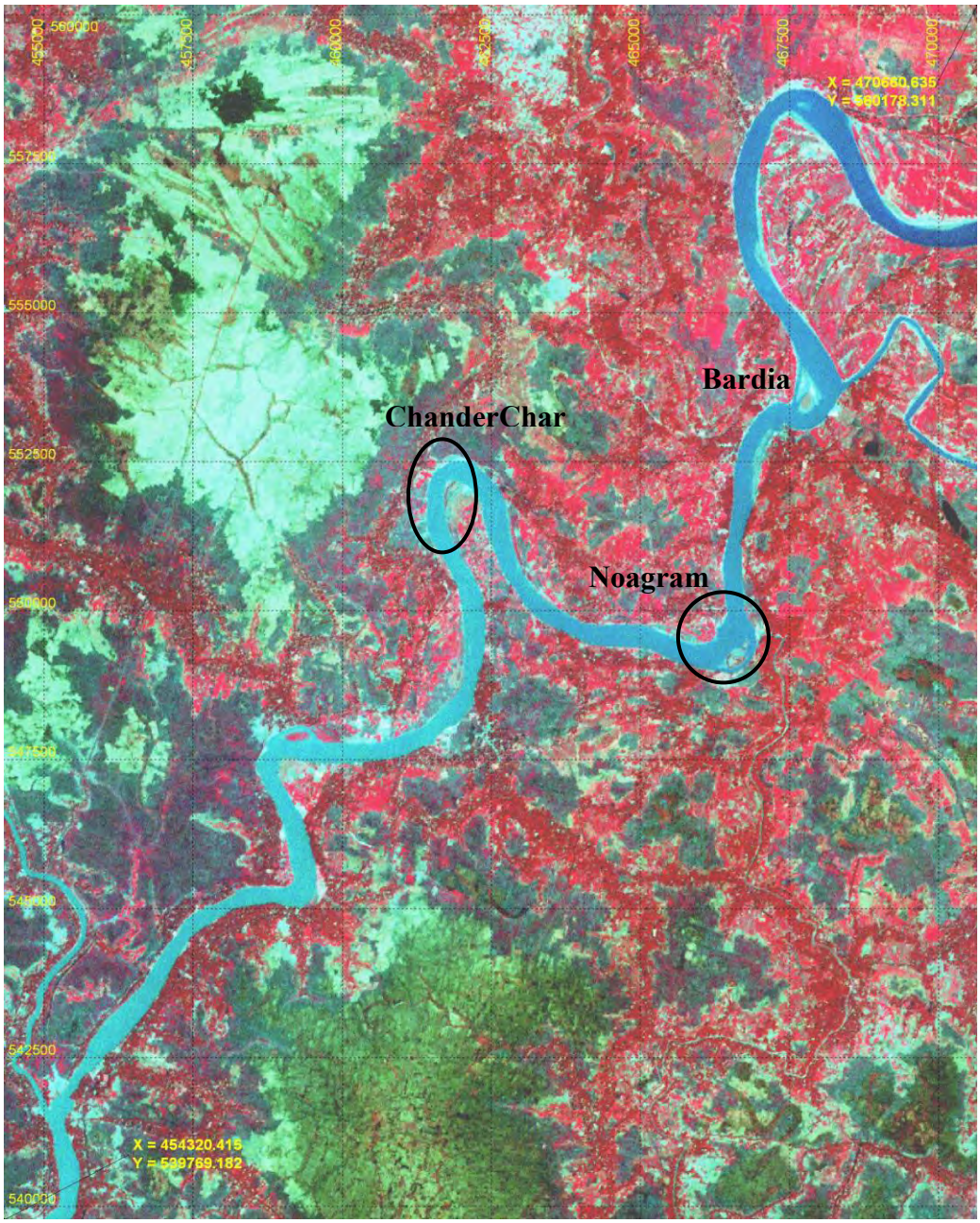


Figure 3.3: Erosion vulnerable locations along the bank of the Nabaganga River (image: 2006)

3.4.2 Water resources

The Gorai River is the main "artery" carrying freshwater through the Nabganga River. The surface water resources along the Nabaganga River are dominated by the Gorai River freshwater flow and tidal flow from downstream control. The regional hydro-morphological regime of the southwest has changed over the past three decades, after the construction and operation of the Farrakka Barrage on the Ganges in India in 1975.

The Gorai River has been the largest perennial distributary of the Ganges in the southwest though its dry season flow suffers since 1989 from great uncertainty due to morphological changes (siltation) at the Gorai off-take. The effects of this uncertain dry season supply is felt along the Nabaganga River as the reduction in freshwater flows has resulted in an increase in salinity levels (see **Figure 3.4**) and migration inland of the saline /freshwater interface (Mohiuddin et. al, 2011). Increased salinity levels along the Nabaganga River and the subsequent introduction of this water onto agricultural land will result in increased soil salinity and a consequent reduction in agricultural production: a further link to poverty and employment issues. Where the Nabaganga river water remains highly saline for longer periods, there will be delays in rice planting and the people can not use the surface water even for domestic purposes.

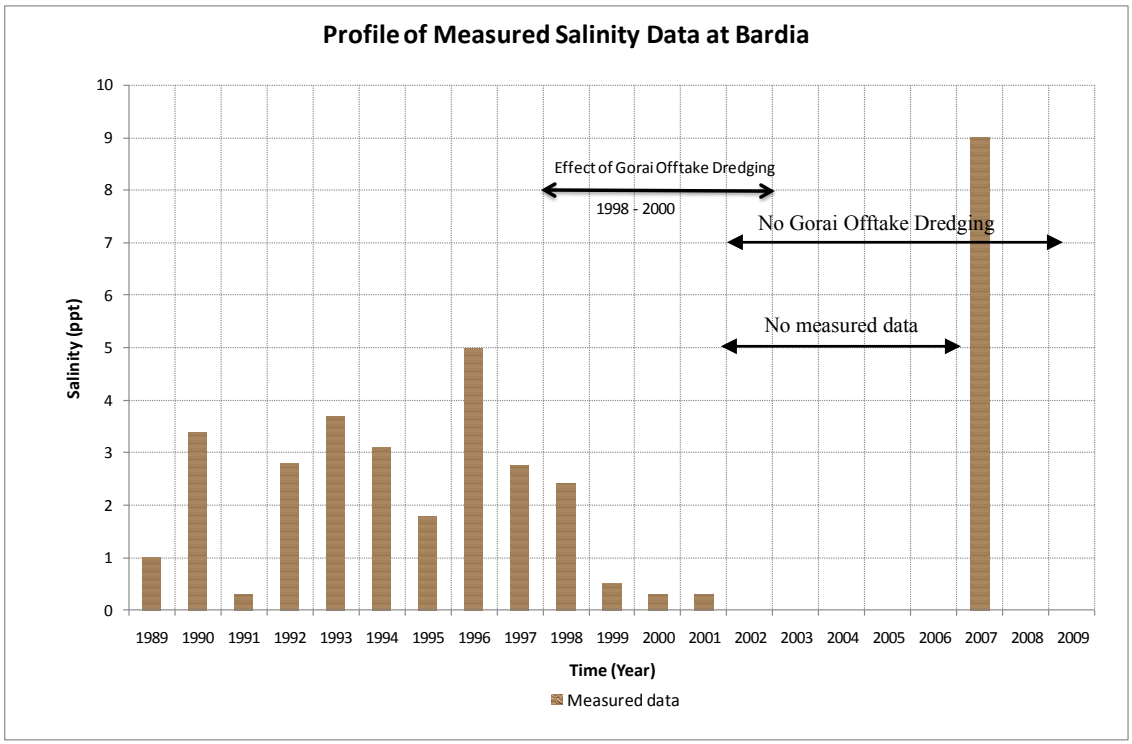


Figure 3.4: Historical propagation of salinity level at Bardia on the Nabaganga River

3.4.3 Water related natural hazards

The water related natural hazards are floods, droughts, cyclone, salinity and river bank erosion. These hazards initially degrade the environment and natural resources within an area. But it has no impact all sections of the community equally or uniformly. The impact on poverty incidence will depend on gender dimensions, asset-ownership

profiles, occupational composition and governance situation which will determine the poverty impact differentials among the cross-sections of various communities (BWDB, 2004). The complex relationship between the river bank erosion and its consequences for the poor at ChanderChar and Noagram is illustrated below:

- All occupational groups residing along the erosion vulnerable bank of Nabaganga River are threatened during the monsoon and feeling insecure;
- River bank erosion causes loss of land, loss of homesteads and embankments/rural infrastructure;
- Loss of land and homesteads leads the poorer groups to reside on the embankments and beside the river in impoverished conditions;
- The erosion affected poorer households often cultivate in the unutilized government low lands beside the river. Due the river bank erosion these sporadic cultivation remain highly vulnerable to erosion.

The erosion and deposition pattern along the Nabaganga River from Bardia based on 1998 and 2006 satellite image data is shown in **Figure 3.5**.

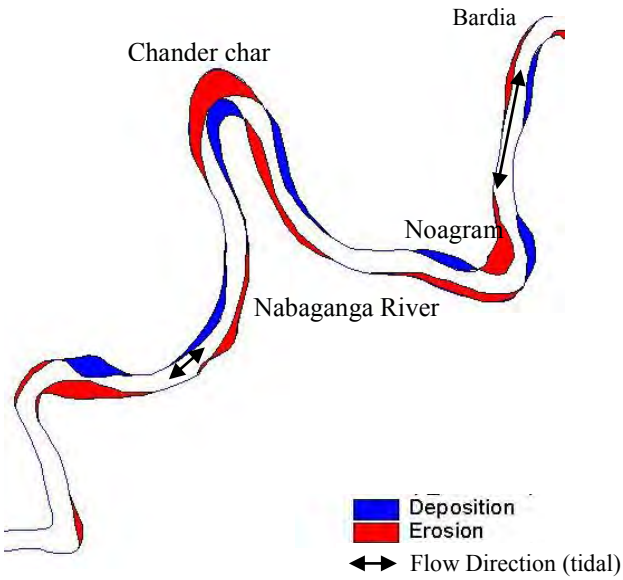


Figure 3.5: Erosion and deposition pattern along the Nabaganga River from Bardia

CHAPTER FOUR

TECHNOLOGICAL MANAGEMENT ASPECTS

Out of six aspects of IRBEM framework, this chapter describes the component of technological management aspects. The important features of this component are prediction method (analytical approach) of river bank erosion rate for the tidal plain, types of erosion risk mitigation measures, assessment of hydraulic design parameters and formulation of implementation plan.

4.1 Prediction Method of River Bank Erosion Rate

The prediction of cohesive riverbank erosion rate and extent is a fundamental problem due to uncertainty of hydraulic controls in fluvial geomorphology. A prediction method of erosion rate in a tidal plain is elemental requirement for the integrated river bank erosion management (IRBEM) framework. Presently, there are many methods (in-terms of empirical, analytical and numerical) available to predict the non-tidal erosion rate and extent. Some of them are academically established such as HEC-RAS and some are used in professional institutes, namely, MIKE21C etc. However, no prediction method has been found during the literature review able to establish the predominant control on the amount of hydraulic erosion rate in response to diurnal tidal flow conditions. It is also found that there is lack of strong correlation between tidal flow conditions and hydraulic erosion due to the typical presence of tension crack in cohesive river banks. In this regard, an attempt has been made to establish the prediction method of erosion rate in a tidal plain based on an analytical approach suggested by Duan (2005).

According to Duan (2005), the rate of bank erosion consists of two processes: (i) basal erosion due to fluvial hydraulics and (ii) bank failure under the influence of gravity which is a probabilistic phenomenon. Because bank resistance force varies with the degree of saturation of bank material, the probability of bank failure is the probability of the driving force of bank failure being greater than the bank resistance force. The degree of saturation of bank material increase with river stage; therefore, the frequency

of bank failure is correlated to the frequency of flooding. This analytical approach includes the analyses of basal erosion, bank failure and probability of bank failure. Moreover, this approach is limited to the homogeneous cohesive bank material experiencing planar bank failure disregarding impact of porosity of bank materials, assuming the depth of tension crack and angle of repose for bank materials.

In this research, above limitations has been addressed by relating porosity with sediment escape velocity; introducing a empirical formula for depth of tension crack proposed by Lambe & Whiteman (1969); for angle of repose proposed by Zhang et al. (1989) relating to median grain size (d_{50}). With this modification a simple method for prediction of river bank erosion rate in diurnal tidal plain has been established showing the calculation of bank erosion rate along the Nabaganga River. In this method curvature effect has not been considered. The timing of bank erosion processes in a tidal river has also been established applying this prediction method.

Basal erosion is referred to as the fluvial entrainment of bank material by flow-induced forces, including drag force, resistance force, and lift force that act on bank surface (Duan, 2005). The concept of basal erosion for cohesive bank material is that bank surface erosion occurs when entrainment of sediment particles from bank surface is greater than deposition. The channel bed or bank remains stable when the exchange of sediment particles between entrainment and deposition reaches a dynamic equilibrium.

The volumetric rate of bank erosion (E_v) due to hydraulic forces is the rate that sediment accumulated or eroded at the bank surface in the horizontal direction. This rate can be calculated as the horizontal projection of the difference between the entrainment and deposition rates as

$$E_v = (E_n - D_n)\sin\alpha \tag{4.1}$$

The volumetric rate of bank erosion (E_v) is the volumetric porous bank material being eroded by hydraulic forces which was included in the calculation of entrainment rate. The entrainment rate, defined as the rate of entrained sediment particles escaping from bank surface with a velocity of V_{sn} perpendicular to bank slope, is calculated as

$$E_n = (1-a)V_{sn} = \frac{(1-a)}{2}\sqrt{\frac{3C'_L\rho}{\rho_s}}\sqrt{u_{*b}^2 - u_{*bc}^2} \qquad (u_{*b} > u_{*bc}) \tag{4.2}$$

Where V_{sn} is the sediment escape velocity from the bank normal to the surface and applying the definition of the critical entrainment Shields parameter (Duan, 2005) and is written as

$$V_{sn} = \frac{1}{2}\sqrt{\frac{3C'_L\rho}{\rho_s}}\sqrt{u_{*b}^2 - u_{*bc}^2} \qquad (u_{*b} > u_{*bc}) \tag{4.3}$$

and E_n is entrainment rate and n is porosity of bank material. In Eq. (4.2), (1 – a) is multiplied by the escape velocity to consider the net amount of sediment entrained from bank surfaces.

The deposition rate can be expressed as the product of near bed sediment concentration and the settling velocity of sediment and is written as

$$D_n = \omega c_b \cos\alpha \tag{4.4}$$

Where, c_b = near bed concentration of moving sediment and

ω = settling velocity of a spherical sediment particle (Van Rijn, 1989)

$$\omega = \frac{2}{\sqrt{3C_D}}\sqrt{\frac{\rho_s - \rho}{\rho} gd} \tag{4.5}$$

Where, C_D = drag coefficient and its value depends on the flow regime being laminar, transitional, or turbulent.

$$\therefore D_n = \frac{2c_b}{\sqrt{3C_D}}\sqrt{\frac{\rho_s - \rho}{\rho} gd}\cos\alpha \tag{4.6}$$

If E_v = 0, then the river bank is not undergoing erosion, so the near bank suspended sediment concentration reaches the equilibrium value. Because $\sin\alpha$ is not a constant and does not equal to zero, the near bed sediment concentration reaches equilibrium when the rate of bank erosion equals to zero. Eq. (4.1) thus yields

$$0=\left[\frac{(-a)}{2}\sqrt{\frac{3C'_L\rho}{\rho_s}}\sqrt{u_{*b}^2-u_{*bc}^2}-\frac{2c_b}{\sqrt{3C_D}}\sqrt{\frac{\rho_s-\rho}{\rho}gd}\cos\alpha\right]\sin\alpha$$

$$c_b=\frac{\frac{(-a)}{2}\sqrt{\frac{3C'_L\rho}{\rho_s}}\sqrt{u_{*b}^2-u_{*bc}^2}}{\frac{2}{\sqrt{3C_D}}\sqrt{\frac{\rho_s-\rho}{\rho}gd}\cos\alpha}=\frac{c_e}{\cos\alpha} \tag{4.7}$$

Where, $c_b=$ equilibrium concentration of suspended near-bank sediment under flow intensity characterized by u_{*b} and $c_e=$ value of c_b when $\alpha=0,$ which equals the equilibrium concentration of suspended near-bank sediment. Therefore, substituting the expression of c_e from Eq. (4.7) into Eq. (4.1), and assuming that the ratio of the actual near-bank sediment concentration and its equilibrium value at $\alpha=0,$ is approximately equal to the ratio of the depth averaged, suspended sediment concentration and its equilibrium value, expressed as

$$\frac{c_b}{c_e}=\frac{C}{C_*} \tag{4.8}$$

Where, C and C_* = depth-averaged and equilibrium concentrations of suspended sediment respectively;

The rate of basal erosion [Eq. (4.1)] becomes

$$E_v=\left[\frac{(-a)}{2}\sqrt{\frac{3C'_L\rho}{\rho_s}}\sqrt{u_{*b}^2-u_{*bc}^2}-\frac{C}{C_*}\cos\alpha\frac{(-a)}{2}\sqrt{\frac{3C'_L\rho}{\rho_s}}\sqrt{u_{*b}^2-u_{*bc}^2}\right]\sin\alpha \tag{4.9}$$

$$E_v=\frac{(-a)\sin\alpha}{2}\sqrt{\frac{3C'_L\rho}{\rho_s}}\left(1-\frac{C}{C_*}\cos\alpha\right)\sqrt{u_{*b}^2-u_{*bc}^2} \tag{4.10}$$

Eq. (4.10) indicates that the depth-averaged concentration of suspended sediment and the local shear stress on the bank are considered the primary factors in determining the rate of basal erosion. The rate of basal erosion varies with the velocity of near-bank friction. To average the rate of basal erosion along the bank surface, shear stress on the surface of the river bank is assumed to be linearly distributed

$$u_{*b}^2 = \frac{\tau_o}{\rho}\left(1 - \frac{y}{h}\right) \tag{4.11}$$

Where, τ_o = shear stress at the toe of the bank slope, and $0 \le y \le h$, where h = flow depth. If the bank is eroding, the actual friction velocity should be greater than the critical friction velocity for bank erosion, which indicated that $u_{*b}^2 \ge u_{*bc}^2$ must satisfy Eq. (4.10); therefore, Eq. (4.10) is valid only when

$$\frac{y}{h} \le 1 - \frac{\tau_c}{\tau_o} \tag{4.12}$$

Where, $\tau_c = \rho u_{*bc}^2$. To obtain the average erosion rate, Eq. (4.10) was integrated from the toe of the bank to $y = h\left(1 - \frac{\tau_c}{\tau_o}\right)$ where the actual friction velocity equals the critical friction velocity. The depth-averaged bank erosion rate is obtained as

$$E_v = \frac{1}{h}\int_0^{h\left(1-\tau_c/\tau_o\right)} \frac{\left(-a\right)\sin\alpha}{2}\sqrt{\frac{3C_L'\rho}{\rho_s}}\left(1 - \frac{C}{C_*}\cos\alpha\right)\sqrt{\frac{\tau_o}{\rho}\left(1 - \frac{y}{h}\right) - \frac{\tau_c}{\rho}}\,dy$$

$$E_v = \frac{1}{h}\frac{\left(-a\right)\sin\alpha}{2}\sqrt{\frac{3C_L'\rho}{\rho_s}}\left(1 - \frac{C}{C_*}\cos\alpha\right)\frac{\sqrt{\tau_c}}{\sqrt{\rho}}\int_0^{h\left(1-\tau_c/\tau_o\right)} 1 - \frac{y}{h} - \frac{\tau_c}{\tau_o}\,dy$$

$$E_v = \frac{1}{h}\frac{\left(-a\right)\sin\alpha}{2}\sqrt{\frac{3C_L'\rho}{\rho_s}}\left(1 - \frac{C}{C_*}\cos\alpha\right)\frac{\sqrt{\tau_c}}{\sqrt{\rho}}\frac{2}{3}h\left(1 - \frac{\tau_c}{\tau_o}\right)^{3/2}$$

$$E_v = \left(-a\right)\sin\alpha\sqrt{\frac{C_L'\rho}{3\rho_s}}\left(1 - \frac{C}{C_*}\cos\alpha\right)\left(1 - \frac{\tau_c}{\tau_o}\right)^{3/2}\sqrt{\tau_c} \tag{4.13}$$

$$E_v = E\left(1 - \frac{\tau_c}{\tau_o}\right)^{3/2}\sqrt{\tau_c}$$

Where, α = averaged bank slope and E_v = depth-averaged bank erosion rate due to hydraulic force. The erosion coefficient E is defined as below that relates to the

porosity of bank material, the average bank angle, coefficient of lift force, and the depth-averaged and equilibrium concentration of suspended sediment.

$$E = (1-a)\sin\alpha\sqrt{\frac{C'_L\rho}{3\rho_s}}\left(1-\frac{C}{C_*}\cos\alpha\right) \tag{4.14}$$

The frequency of bank failure correlates to the frequency of flooding. The rate of bank erosion is determined by the size of the bank failure block and equals the width of the bank failure block divided by the total time required for basal erosion, T_s and bank failure, T_f, can be expressed as

$$E_r = \frac{\Delta B}{\Delta t} = \frac{\Delta B}{T_s + T_f} \tag{4.15}$$

Where $\Delta B =$ width of failure block;

$\Delta T = T_s + T_f =$ total time required for both basal erosion and bank failure;

$T_s =$ time for a stable bank to reach a critical state of bank failure caused by basal erosion; and

$T_f =$ period of bank failure.

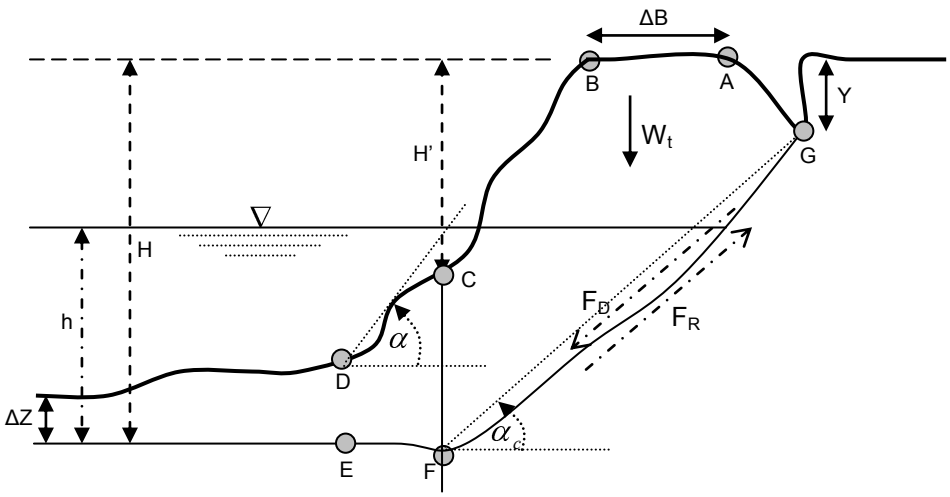


Figure 4.1: River bank erosion to the point of failure

At the critical condition, CDEF in **Figure 4.1**, is the mass volume eroded by fluvial entrainment per unit channel length

$$V_s = \frac{1}{2}\frac{\left[(H-H')^2 - \Delta Z^2\right]}{\tan\alpha} = \frac{1}{2}\frac{(H-H')^2}{\tan\alpha} \qquad \Delta Z \le H - H' \tag{4.16}$$

Where V_s = mass volume of eroded sediment by entrainment per unit width;

H = bank height at the critical condition;

H' = is the bank height above the zone of lateral erosion; and

β = angle of failure plane.

The volumetric basal erosion rate is the product of rate of basal erosion and the height of the erodible bank surface, i.e. $(H - H')E_v$. The time required for the bank surface to reach the critical bank failure condition, T_s, equals the total eroded sediment volume divided by the volumetric basal erosion rate, i.e.,

$$T_s = \frac{V_s}{(H - H')E_v} = \frac{\frac{1}{2}\frac{(H - H')^2}{\tan\alpha}}{(H - H')E_v} = \frac{(H - H')}{2E_v \tan\alpha} \tag{4.17}$$

Bank failure occurs when the critical condition of bank failure is reached, and a flood event is assumed to trigger the failure. The width of the failure block (Osman and Thorne, 1988) is given as

$$\Delta B = \frac{H - Y}{\tan\alpha_c} - \frac{H'}{\tan\alpha} \tag{4.18}$$

Where, Y = depth of the tension crack and ΔB = distance of bank retreat due to bank failure.

The depth of tension crack (Y) is usually equated to the depth at which the active pressure is zero according to Lambe & Whiteman (1969):

$$Y = \frac{2c'}{\gamma}\tan(45^0 + \phi'/2) \tag{4.19}$$

where, γ = bulk soil unit weight (kN/m^3);

c' = effective cohesion (Pa);

ϕ' = effective internal friction angle, deg;

The angle of the failure plane could be determined according to Osman and Thorne (1988):

$$\alpha_c = \frac{1}{2}\left\{\tan^{-1}\left[\left(\frac{H}{H'}\right)^2 \left(1 - K^2\right)\tan\alpha\right] + \phi\right\} \tag{4.20}$$

Where, $\phi =$ angle of repose;

$K = Y / H =$ ratio of crack depth to bank height.

The angle of repose for bank material at the lower bank surface was calculated by using an equation derived by Zhang et al. (1989) whereby extensive laboratory experiments involving various sized sediment were used:

$$\phi = 32.5 + 1.27 * d_{50} \tag{4.21}$$

where, $\phi =$ angle of repose in degree ( ) and d_{50} represents median grain size (mm).

The rate of bank erosion is the product of two factors: one is the depth-averaged rate of basal erosion and the other is the coefficient of bank failure.

$$E_r = \frac{\Delta B}{\Delta t} = \frac{\Delta B}{T_s + T_f}$$

$$E_r = \frac{\dfrac{H-Y}{\tan\alpha_c} - \dfrac{H'}{\tan\alpha}}{\dfrac{(H-H')}{2E_v\tan\alpha} + T_f} = \frac{\dfrac{H-Y}{\tan\alpha_c} - \dfrac{H'}{\tan\alpha}}{\dfrac{(H-H')}{2\tan\alpha} + E_v T_f} E_v = eE_v \tag{4.22}$$

Where, $e =$ coefficient that reflects the effect of bank failure considering the critical bank height, *H*; depth of tension crack, *Y*; the angle of failure plane, α_c; period of bank failure, T_f; and the average bank slope, α.

$$e = \frac{\dfrac{H-Y}{\tan\alpha_c} - \dfrac{H'}{\tan\alpha}}{\dfrac{(H-H')}{2\tan\alpha} + E_v T_f} \tag{4.23}$$

The critical bank height, H, could be determined following the relation according to Osman and Thorne (1988)

$$H = H' \frac{\left[\lambda_2/\lambda_1 + \sqrt{(\lambda_2/\lambda_1)^2 - 4\lambda_3/\lambda_1}\right]}{2} \tag{4.24}$$

Where,

$$\lambda_1 = (1 - K^2)(\sin\alpha_c \cos\alpha_c - \cos^2\alpha_c \tan\phi) \tag{4.25}$$

$$\lambda_2 = 2(1 - K)\frac{c}{\gamma_s H'} \tag{4.26}$$

$$\lambda_3 = \frac{\sin\alpha_c \cos\alpha_c \tan\phi - \sin^2\alpha_c}{\tan\alpha} \tag{4.27}$$

Where, λ_1, λ_2 and λ_3 = coefficient

c = cohesive coefficient with the consideration of safety factor in Osman and Thorne (1988);

γ_s = specific weight of bank material;

$K = Y/H$ = ratio of crack depth to bank height;

The frequency of bank failure is needed in Eq. (4.23) to approximate the rate of bank erosion. Because the bank collapses when the drag force of the failure block is greater than the resistance force, the probability of bank failure is interpreted as the probability that the driving force of bank failure is greater than the bank resistance force. According to the analysis of Osman and Thorne (1988), the weight of the failure block is

$$W_t = \frac{\gamma_s}{2}\left(\frac{H^2 - Y^2}{\tan\alpha_c} - \frac{H'^2}{\tan\alpha}\right) \tag{4.28}$$

The cohesive bank resistance force of bank material as a function of bank height, length and depth of tension crack, angle of failure plane, depth of flow and resistance of cohesive bank material. The resultant criterion of bank failure is obtained as

$$h > \frac{(H - Y)c_d}{\Delta c}\left[1 - \frac{\sin\alpha_c}{H - Y}\frac{1}{c_d}(W_t \sin\alpha_c - W_t \cos\alpha_c \tan\phi)\right] \tag{4.29}$$

Then, Eq. (4.29) can be rewritten into a simple form as

$$h > h_p \tag{4.30}$$

Eq. (4.30) indicates that when flow depth is greater than h_p , drag force will exceed resistance force and bank failure will occur. The probability that flow depth is greater

than h_p occurs when the driving force of bank failure is greater than the bank resistance force. By defining the flow depth with p occurrence probability as

$$hp = \frac{(H - Y)c_d}{\Delta c}\left[1 - \frac{\sin\alpha_c}{H - Y}\frac{1}{c_d}(V_t \sin\alpha_c - W_t \cos\alpha_c \tan\phi)\right] \tag{4.31}$$

The relationship between flow depth and discharge for turbulent flow can be determined by the Manning equation as follows:

$$Q_p = \frac{1}{n} h_p^{2/3} I^{1/2} A \tag{4.32}$$

The time required for a bank failure to occur is

$$T_f = \frac{1}{\eta} \tag{4.33}$$

Where, η is probability that flow discharge is greater than the critical discharge of bank failure, which equals the probability of bank failure.

Calculation of Bank Erosion Rate along the Nabaganga River:

The bank erosion rate equation, Eq. (4.22) requires geometrical bank parameters (i.e., bank height, bank angles, bank material properties), hydraulic parameters (i.e., flow velocity, roughness, bed slope), and a time series of discharge records. In this research, two erosion vulnerable sites namely, ChanderChar and Noagram have been selected along the bank of the Nabaganga River (see **Figure 4.2**).

The following data sets have been collected from the project of BWDB, namely, "South West Area Integrated Water Resources Planning & Management: Bangladesh"**:**

- Water level & discharge data for 2008 monsoon condition at ChanderChar and Noagram erosion prone area of the Nabaganga River;
- River cross-sections at different time-frame of 2008 monsoon at ChanderChar and Noagram erosion prone area of the Nabaganga River;
- Bank line of erosion prone area at ChanderChar and Noagram;

In addition, following data has been collected from IWM**:**

- Historical water level & discharge data at Bardia on the Nabaganga River;

- 1D model generated data to compare the water level, discharge & velocity data at ChanderChar and Noagram erosion prone area of the Nabaganga River;
- Historical satellite imagery of the Nabaganga River;
- Grain size of river bed materials & bank materials of the Nabaganga River;

The following key data sets has been used to determine the bank erosion rate at ChanderChar area for 2008 monsoon condition from July to September:

- Average initial bank angle ~ 68 degree;
- $(d_{50})_{bank}$ = 0.105 mm;
- $(d_{50})_{bed}$ = 0.065 mm;
- The ratio between actual and equilibrium concentration of suspended sediment ~ 0.32 (assumed based on few concentrations data);
- Manning's roughness coefficient ~ 0.0117;
- Silt-clay percentage ~ 5.8%;
- Nabaganga River slope ~ 7-8 cm/km;
- Particular cross-section properties of eroded vulnerable reach;
- Simulated water level and discharge time series from July to September 2008 instead of discontinuous measured data;

The analytical result indicates that the hydraulic characteristic of bank erosion is quite different in the tidal plain than the non-tidal plain. In the non-tidal plain, continuous bank erosion occurs when the discharge exceeds its critical value or the flow exceeds its erodible velocity (see **Figure 4.3**). In the tidal plain, the bank erosion occurs at the mid of ebbing while eroded velocity exist in the river up-till the low water slack time (see **Figure 4.4**). Bank erosion occurs two times in a day due to diurnal tide in Bangladesh. The calculated bank erosion rate and measured bank erosion rate at ChanderChar has been given along the eroded bank as shown in **Figure 4.5**. The calculated accumulated bank erosion rate (see **Figure 4.6**) using the above mentioned method from July to September 2008 at 0.6 km location of the eroded bank is 60 m, which corresponds to the observed values. The discharge time series of 1D hydrodynamic model has been used for continuous calculation from July to September 2008, because the observed data is discontinuous.

The erosion early warning sub-plan could be established on the basis of predicted erosion rate and extent, social vulnerability of the elements at bank erosion risk.

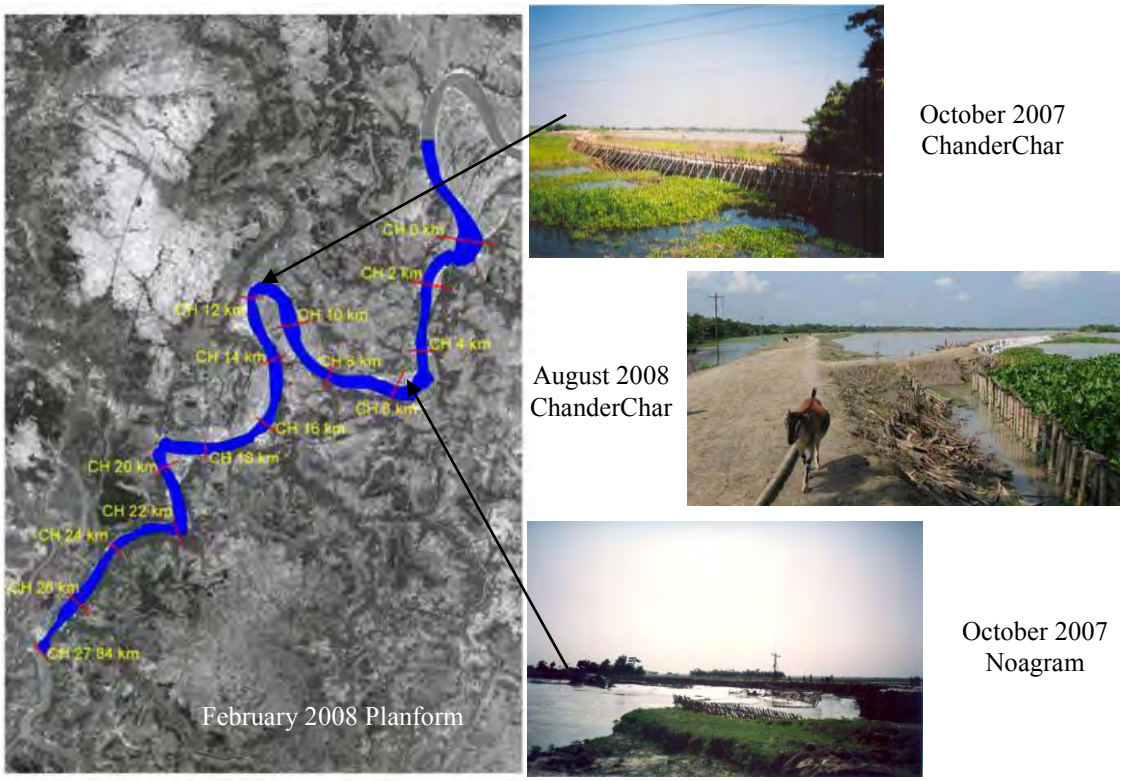


Figure 4.2: Erosion vulnerable sites at ChanderChar and Noagram on the Nabaganga River

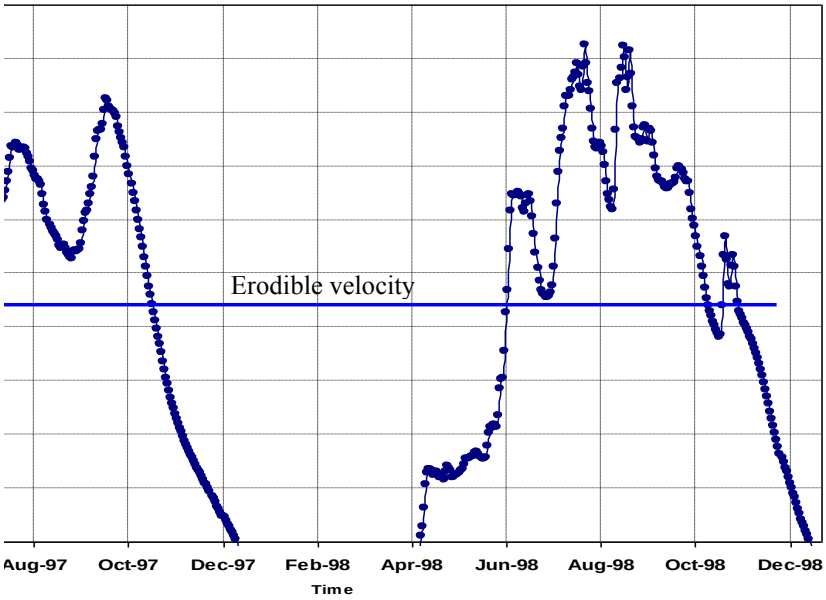


Figure 4.3: The continuous bank erosion occurs during monsoon when the erodible velocity exists in the non-tidal plain

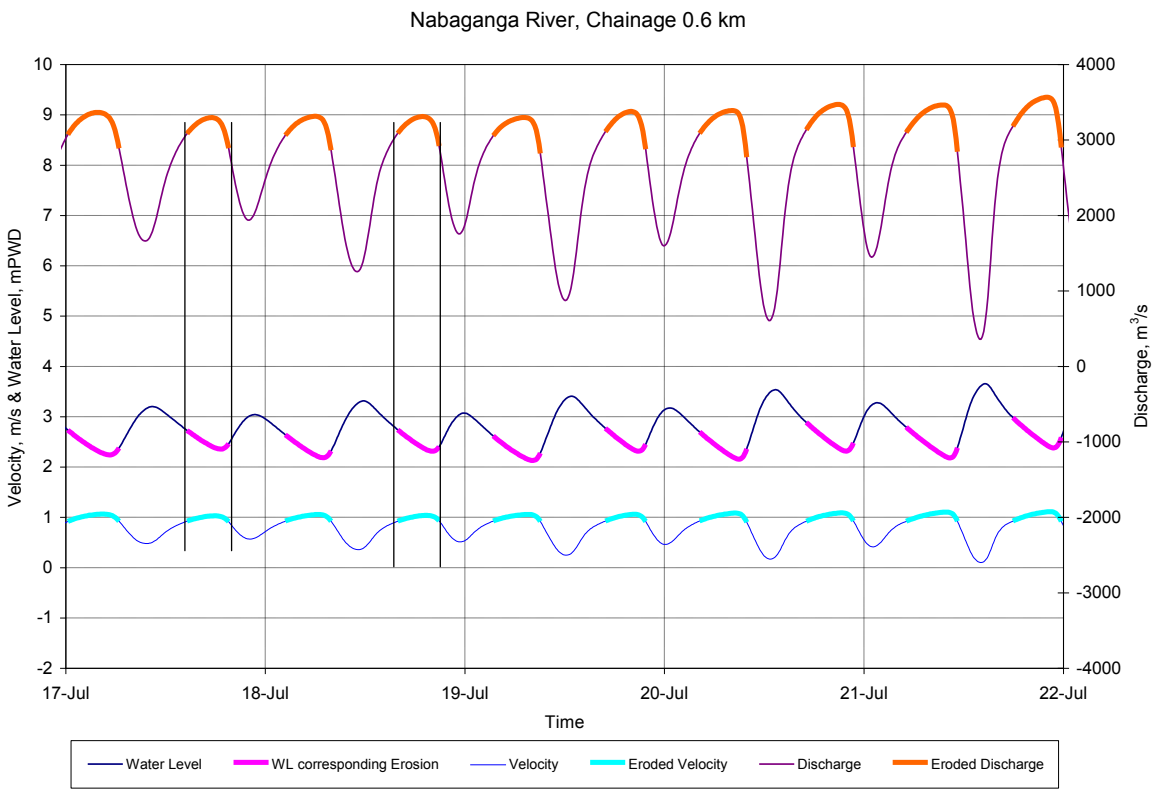


Figure 4.4: The hydraulic characteristic of bank erosion at ChanderChar in the Nabaganga River, erosion occurs two times in a day due to diurnal tide

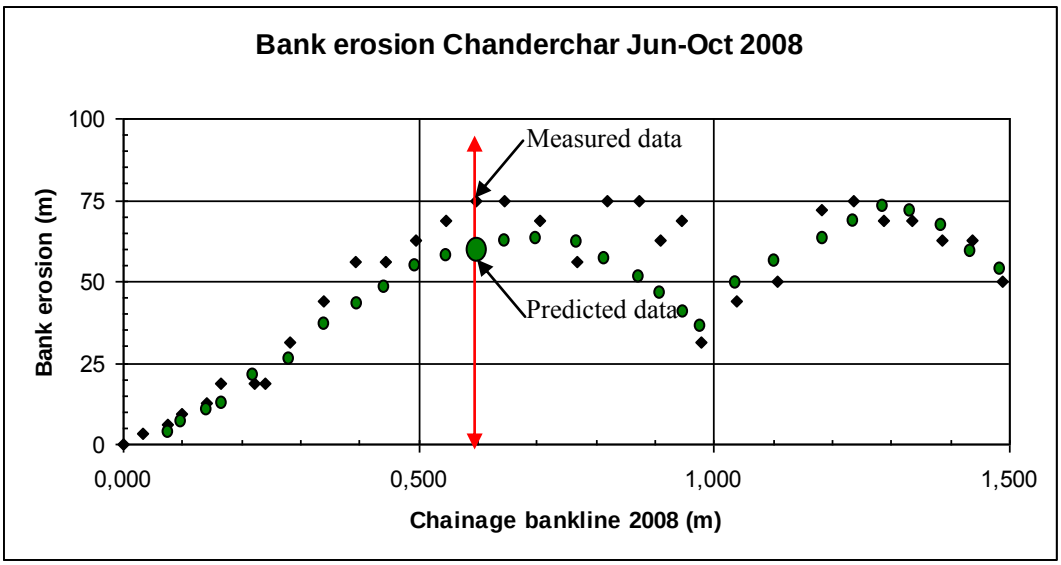


Figure 4.5: Measured and predicted (using above mentioned analytical approach) bank erosion rate at ChanderChar along the Nabaganga River

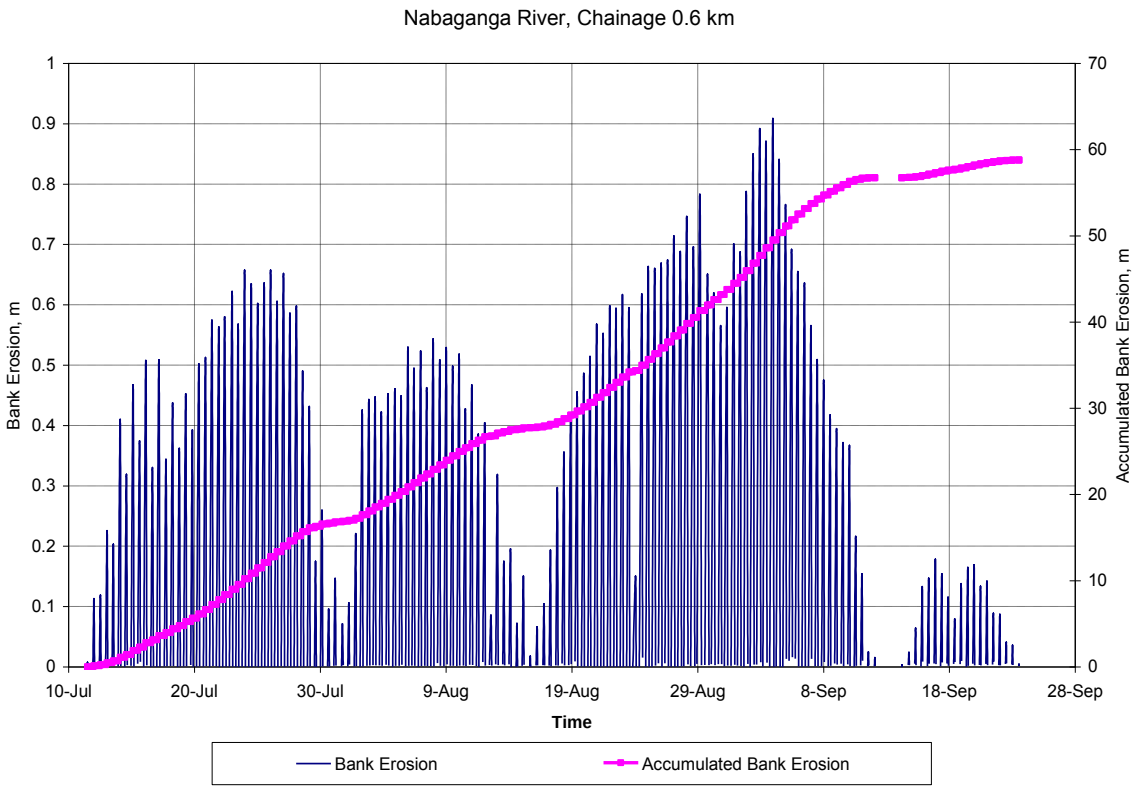


Figure 4.6: Calculated accumulated bank erosion from July to September 2008 at ChanderChar

4.2 Bank Erosion Risk Mitigation Measures

4.2.1 Bank erosion risk assessment

An interdisciplinary approach is required for the development and successful implementation of bank erosion mitigation measures and its design, construction and maintenance. To achieve the aim of IRBEM framework all relevant aspects are needed to be handled by a single integrated team under an institutional framework working in partnership including stakeholders. In Bangladesh, people may be able to adapt to recurrent flooding, but they find riverbank erosion difficult to cope with. Social impacts on river bank erosion include increased impoverishment and landlessness, loss of income generation, migration of displaced population reduced security and social displacement. These social impacts could be assessed by analyzing the social factors and social vulnerability indicators (see Social Management Aspects – Chapter 5) on the basis of predicted bank erosion rate and its extent.

River bank erosion causes disaster for many families at ChanderChar and Noagram along the right bank of the Nabaganga River. As such sustainable and reliable riverbank protection work is a key element in providing safe and stable living conditions along the densely populated banks of the Nabaganga River. As bank protective work is capital intensive, there is strong quest for economically feasible and sustainable bank protection methods. Consequently, it is important to understand the erosion risk in-terms of magnitude of erosion hazard, exposure of human activities to erosion and the vulnerability of the elements at risk (see Risk Management Aspects – Chapter 6) on the basis of predicted bank erosion rate and its extent.

Sustainable bank protection reduces the risk of disaster – the loss of lands, infrastructure and provides stable living conditions. In this approach vulnerability according to the erosion prediction could be analyzed and categorized risk zone as "high", "medium" and "low". Moreover, the anticipated morphological risk could be assessed making correlation with hydraulics are (a) upstream bend development, (b) downstream bend development, (c) severe channel attack and also structural risk for any river bank erosion mitigation measure like (i) improper launching of apron material, (ii) slope failure, (c) unusually high scour etc. To address all these potential risks continuous monitoring and evaluation is required and provision should be made to address all these probable risks in IRBEM framework.

4.2.2 Type of mitigation measures

Risk assessment is a fundamental requirement to select the type of mitigation measures. Bangladesh finds it difficult to protect long reaches of its eroding bank-line using sustainable bank protection structures which are very costly. The need is therefore to identify alternative concept and materials for erosion mitigation that would prove cost effective even for protecting agricultural land. This need can be met by using an "Adaptive Approach" that stabilizes the riverbank along an alignment natural to the river system. The riverbank erosion management in Bangladesh should be addressed in a way that assures the proper measure in right time. An Adaptive Approach, which means that interventions are planned according to the observed and predicted river behavior (BWDB, 2008). Moreover, a comprehensive riverbank erosion management approach is required to provide living conditions along the banks, protecting existing infrastructure, enhancing economic activities and reducing poverty. The comprehensive

approach may comprise: (i) structural riverbank protection protection (revetment, groin/spur, hard point etc.), (ii) non-structural measures (resettlement, rehabilitation etc.) mitigating negative impacts, (iii) erosion disaster preparedness and management, (iv) social support to vulnerable poor, and (v) socially and environmentally acceptable joint floodplain management through stakeholders' participation and government agency.

4.2.3 Applicability of mitigation measures

After selecting the type of mitigation measures, it is very much essential to judge the applicability based on its prioritization criteria. River bank erosion predictions and their proper dissemination to national and local organizations as well as to communities have a great potential to enhance water resources planning both at macro and micro levels, reducing national losses and suffering of erosion vulnerable people. The identification of the appropriate mitigation measures for the riverbank erosion and subsequent need for stabilization is best accomplished through observation.

Prediction of erosion and morphological changes one year ahead with different probabilities can be of much help for taking care of certain unusual situations that may occur in next monsoon. Preparatory activities of the Government for facing the probable calamities through erosion may be of great help to overcome the difficulties in proper time and sequence. In this regard, the monitoring unit of BWDB who will be responsible for prediction of bank erosion should have close liaison with the planning and design unit.

In view of the limited fund available not all places vulnerable to erosion can be protected at a time. Hence, prioritization of the work needs to be done through combining the warning of erosion prediction and the pre-determined erosion criteria, which may follow the guidelines like importance of the place or structure to be saved, severity of attack and consequences of not protecting the bank immediately. The prioritization criteria may be:

a. defend existing protective work
    - measure against outflanking of an existing bank protection structure;
    - repair of damaged bank protection structures;

b. defend infrastructure
   - protection of important highway/railway links;
   - protection of place of historical importance;

c. protection against drastic environmental changes
   - protect river course that may endanger stability of environmentally important places and cause environmental imbalance;
   - protect agricultural land/homestead/growth centers etc.

All the alternatives may be examined by a committee of experts to achieve the desired goals and select the suitable mitigation measures on the basis of their socio-economic aspects. Moreover, riverbank erosion management should be taken care of in a timely and strict coordinated manner using (i) prediction methods, (ii) observation and again observation, (iii) under water investigation through river surveys, and (iv) detail and integrated analysis of data.

4.3 Design Parameters of Bank Protection Work

The following design parameters need to be assessed to design the adequate erosion mitigation measures:

Hydrologic and hydraulic parameters:
The related parameters are water levels, discharge, current or velocity and waves. Normally, the recurrence period can be taken as 30 to 50 years, but 100 years return period can be taken for important protection work. For the design of bank protection structures in the tidal plain, the maximum and minimum water levels are important. Therefore, SLW (standard low water), SHW (standard high water), and DHW (design high water) are defined for the location of the protection site. The definition of SLW and SHW in Bangladesh is the 5% non-exceedence level and 5% exceedence level respectively.

Morphological parameters:
General parameters related to morphology of rivers are slope, width, mean depth, particle size, sediment transport, bankfull discharge, dominant discharge etc. Other important parameters in a tidal plain river are:

- Plan-form characteristics;
- Shifting and widening of the river;
- Bend characteristics and cutoff;
- Channel cross-section and scour depth;
- Location of nearby bank protection or river training structures in the vicinity of the erosion vulnerable site;

All these hydraulic design parameters are needed to be analyzed to design adequate erosion mitigation measures.

In Bangladesh, revetment and groin are frequently used as bank protection work. The purpose of bank revetment and groin is to prevent bank erosion that means they have to design to resist the current and wave and to protect the river bed and river bank against changes. Their principal function is to provide a stable river bank. To fulfill this role they must meet the following design criteria as design parameters, such as design discharge, the maximum, minimum and standard low water levels, flow velocities, wind speed and wind waves, design scour depths and morphological changes.

4.4 Implementation Plan for Bank Protection Work

An implementation plan should be designed with "Adaptive Approach" covering execution timing, extent of protection work phasing, monitoring and evaluation phase. An adaptive approach means to provide protection initially to the most vulnerable reach and make provision, including design concept and fund allocation, including taking care of any sudden increase in erosion attack in the adjacent reaches of the river in the subsequent time. This approach would allow an opportunity to limit the initial capital investment and use the additional provision only when there is need.

Timing: In Bangladesh, the appropriate time for implementation of river bank protection work is December to April. Therefore, design and tendering work including fund allocations needs to be completed before November, then the Contractor can be fielded in December to construct the required mitigation measure in ample right time.

Extent of protection work: during the planning and design phase – extent of protection work has to be designed on the basis of predicted erosion rate and its extent, evaluation of socio-economic aspects including stakeholder concerns'. Provision should be kept for monitoring river behavior and reaction of protection structures shall be the core duty of the person responsible for implementation and maintenance of such protection work.

Monitoring and Evaluation: monitoring and evaluation can play an important role for improvement of design and construction methodology in later stages. Monitoring has to be accepted as a continuous process until a cost effective and sustainable solution for bank protection is achieved.

In order to record the response of the river with the bank protection work and also the morphological changes afterwards systematic and well documented monitoring of the river behavior is required both during the implementation and also during operation of the structure (BWDB, 2008). Benefits of regular monitoring are:

- Indication in sudden erosion in the embankments and the monitoring data provide a valuable basis for planning of future protection work;
- Indication on failure of bank slopes from geotechnical point that might be triggered by seepage or piping;
- Provides an early warning system, when unfavorable situations are detected.

Monitoring of river provides the data on morphological behavior of the river and in this regard following data is required:

- Bathymetric survey – at the end of each monsoon, verify the morphological prediction of river changes and provide baseline data for work during dry season;
- Bankline survey – at the end of each monsoon, verify the erosion prediction;
- Flow tracking and measurement of flow velocity needs to carried out pre-monsoon, during monsoon and post-monsoon around all protection structure at least for a length of 5 km covering both upstream and downstream.

Another part is maintenance means primary repair/reinforcement of weak or damaged part of a structure and also is part of the management of the hydraulic structure that

mainly includes inspection and repair. If the identification of any damages is not done regularly and repair is not done in time, major damage may happen any time requiring reconstruction/rehabilitation involving huge cost in the long-run.

4.5 Schematic Frame of Technological Management Aspects

The functional relationship between outputs of this aspects and inputs of other aspects is shown **Figure 4.7**. A schematic frame of technological aspects considering all functional outcome stages is illustrated in **Figure 4.8**. In this frame, technological aspects have been demonstrated by establishing a functional relationship in between prediction of river bank erosion rate, risk identification approach, type of mitigation measures, design considerations and implementation plan. Moreover, this frame establishes an interactive approach for pre-erosion & post-erosion management operations with erosion emergency management operations by introducing the monitoring and evaluation technique.

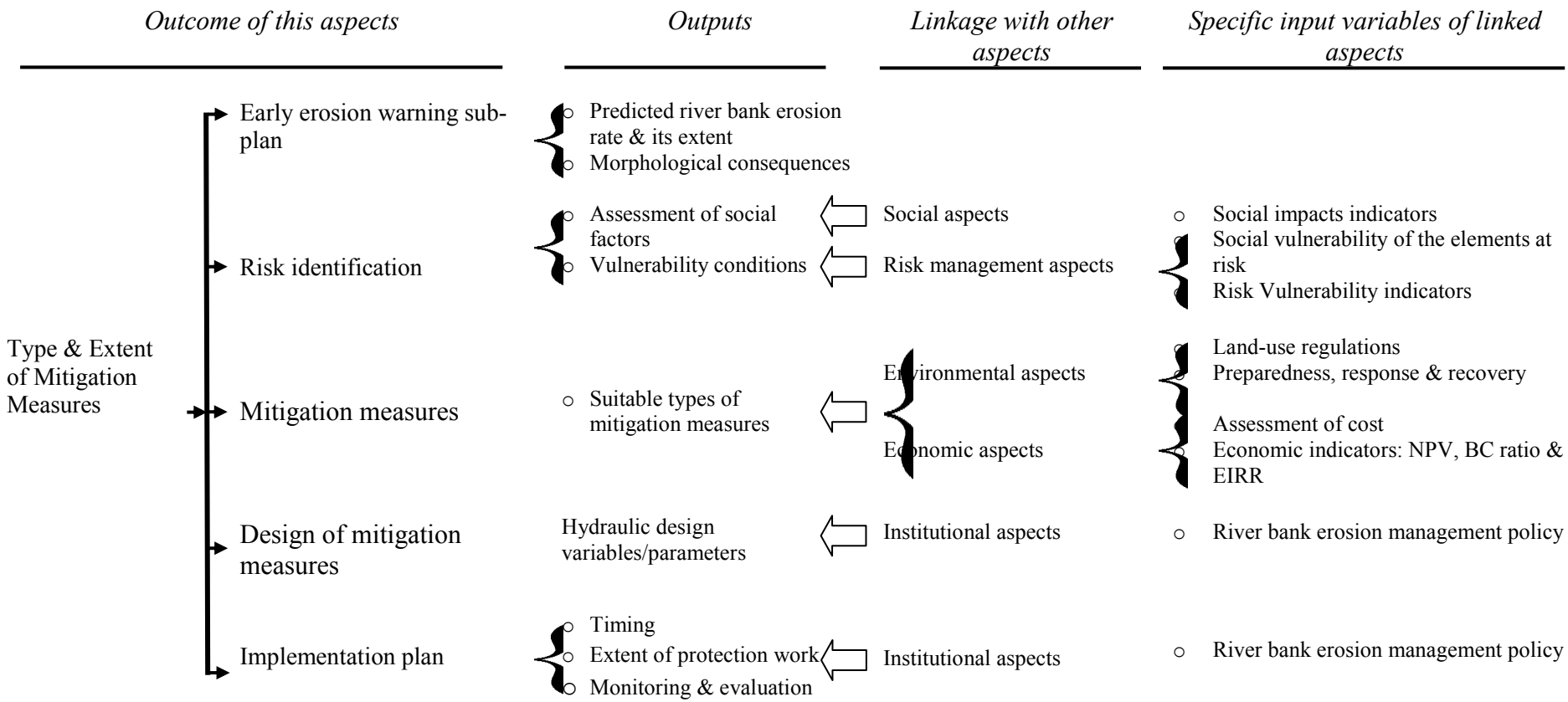
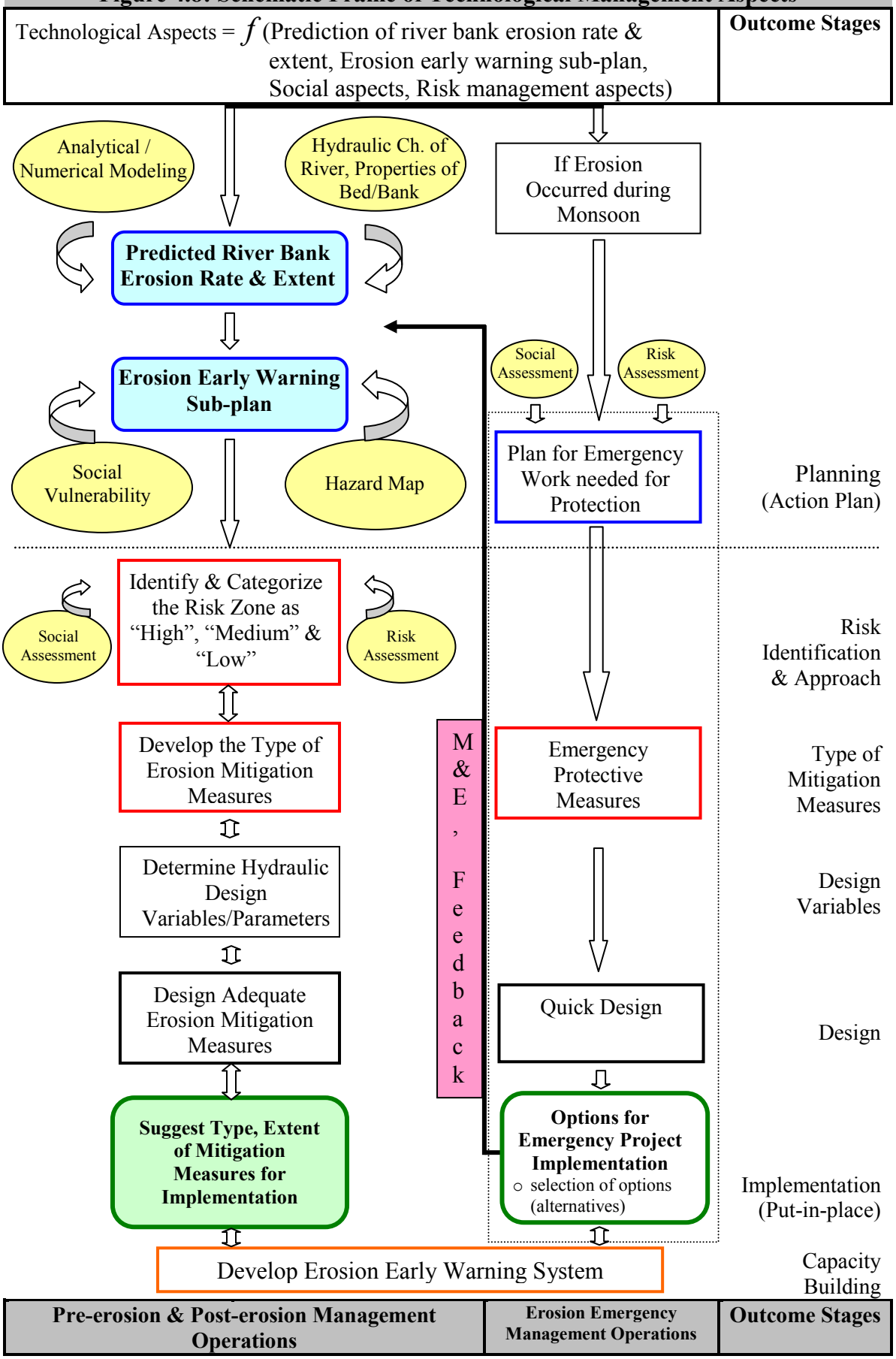


Figure 4.7: The functional relationship between input and output of independent and dependent variables

Figure 4.8: Schematic Frame of Technological Management Aspects



CHAPTER FIVE

SOCIAL MANAGEMENT ASPECTS

Out of six aspects of IRBEM framework, this chapter describes the component of social management aspects. The main purpose of social aspects is to assess social perception on river bank erosion, social impact indicators influencing erosion vulnerability, identification of stakeholders and its response and finally river bank erosion management operations based on social perceptions.

5.1 Social Response on River Bank Erosion

The river bank erosion is a natural phenomenon which considered as a barrier to economic development of the eroding vulnerable community. It has linkages with hydrological events occurs in the river system, environments and ecosystems of the floodplains, socio-economic condition of the inhabitants. It is also observed that the lifeline of the major population living along the eroding river bank facing extreme poverty. Therefore, understanding of social response including indigenous knowledge is very much inevitable to develop an integrated approach for river bank erosion management. The integration means a judicious combination of measures covering structural and non-structural solutions depending on the social response. Considering these facts, IRBEM requires an understanding of social response on bank erosion hazards, magnitude of erosion risks and vulnerability of those risks. The social responses have been assessed by developing a stakeholder mechanism for IRBEM considering the issues of social perception and social impact indicators contributing erosion vulnerability.

5.1.1 Causes of river bank erosion

The river bank erosion is a natural hazard. The causes of such hazard could be assessed through interaction of the natural resource management with the social, economic and environmental resource management. As a result, an integrated approach to erosion management requires an understanding of societal vulnerability to erosion hazard and hydraulic characteristics of bank erosion and the reaction on society about mitigation measures. Understanding from literature and field data investigation various

hydrological, hydraulic and human factors that contribute to bank erosion in the tidal plain are listed in **Table 5.1**.

Table 5.1: Factors contributing to river bank erosion

Hydrological Factors	Hydraulic Factors	Human Factors
o Floods / floods frequency o Tidal characteristics o Soil moisture level o Climate change	o Channel cross-sectional shape & roughness o Bed & bank material characteristics o Near bank velocity o Wave action due to wind	o Structural erosion control measures such as embankments, revetments, spur/groyne etc.

According to local erosion victim people at ChanderChar and Naogram along the bank of the Nabaganga River, the main causes of bank erosion is that tremendous velocity at the bend during the month of August and September (Srabon, Vadra & Ashmin in Bangla), secondary current (vortices) effect causes the soil erosion at the toe of the bank. Erosion generally occurs at the middle of ebbing and continues up till at the start of flooding when tremendous velocity generates at the bend with a great noise. Erosion also occurs almost in every year in this two locations and magnitude, extent of the erosion depends on the floods / floods frequency.

5.1.2 Social perception on river bank erosion

In Bangladesh, near bank floodplains have been used for human settlements and growth-centers. As a result, river bank erosion damage generates direct impact on socio-economic status in-terms of losses of land, people's income and safety. This is due to increase population growth rate, decentralization of investment up to LGI following top-down management approach and inadequate knowledge of bank erosion risks and its protection mechanism.

The erosion control has largely relied on structural solutions, such as revetments, spurs and groins. The river bank erosion protection measures have played an important role in protecting land, people and socio-economic development from bank erosion. The present practice of erosion control in Bangladesh has been engineering centered. No consideration being given to the social, cultural and environmental impacts on economic sustainability. River bank erosion issues are influenced by the overall social, economic and environmental setting of the region rather than physical causes of erosion. Consequently, these issues have been addressed within the framework of

social, environmental and economic management aspects. In this context, two major apprehensions are: (a) ensuring minimum disruption and disturbance to socio-economic activities and livelihoods while implementing erosion mitigation plan and (b) ensuring impartial mitigation measure in erosion prone areas.

The social issues has been addressed in this framework attempts to answer questions relating to bank erosion, social risk, environment preservation, ensure livelihoods and economic development. In this regard, stakeholder consultations have been carried out through discussion/public hearings and focus group discussion (FGD) at ChanderChar and Noagram. According to the erosion victim peoples, river bank erosion produces a variety of negative impacts in the socio-economic activities. The magnitude of adverse impacts depends on the vulnerability of the activities, population growth and frequency, intensity and extent of bank erosion.

5.1.3 Social impact indicators contributing bank erosion vulnerability

By analyzing the collected data and information it is revealed that the relevant social impact indicators to bank erosion management are demographic features, loss of livelihoods, income and poverty, and women sufferings. The standardization of indicators is given in **Appendix-B**. The following conclusion has been made based on the collected social survey data/information taken at ChanderChar and Noagram to determine community vulnerability.

Demographic features:
The identified labels of demographic features in connection with bank erosion management are no. of adult in a family, no. of earners in a family, age group of each household and change occupation. It is observed that most of the household has two adult persons out of 4-6 members' family where only one person is earner. The average age of household head is less than 50 years. The change occupation indicates that the river bank erosion has immediate impacts on loss of physical land, property, crops, human lives, livestock and damage of infrastructure facilities. Short-term impacts include people became landless, homeless and turn into a day-labour from agricultural, fisheries and other sectors. Long-term impacts include people were migrating towards the road / embankment side in the same village or nearby village or nearby Upazila / District town. Even some of the peoples were migrating towards the capital city, Dhaka

and Mumbai, India. In tidal plain bank erosion cause more loss than slow rising non-tidal plain with no warning time. Losses caused by bank erosion are directly proportional to the magnitude and extent of bank erosion and vulnerabilities of socio-economic activities. The extensive losses include the rehabilitation and recovery costs due to bank erosion.

Erosion victim people at ChanderChar put their views as some landless people were migrated towards Mumbai, India to secure their livelihood as day-laborer. Some of them at Noagram also opined that they don't have much more time or warning time when severe bank erosion occurs.

Loss of livelihoods:

The identified labels for loss of livelihoods are work availability, agricultural mobility, non-agricultural mobility, women income, land loss, homestead and employment motivation. It is observed that work availability has changed drastically less than 3 days a week with agricultural and non-agricultural mobility partially turned into other labour. Sometimes income of women has totally lost or partially lost. In erodible bank floodplain communities, those depending on agricultural activities were facing severe trouble. They were put out of work for a long-time and changed their profession into a day-labour. The bank erosion effects of the loss of livelihoods in the sector of agriculture, small business and other commercial activities.

The major livelihoods of communities living in erosion vulnerable floodplains along the Nabganga River are mainly agricultural farming, small business and fishing. The recurrent bank erosion causes loss of land, property and threatens the stability of their livelihoods by limiting access to the market. After bank erosion, the landless poor working as hired labourers facing trouble finding new jobs to meet their basic needs. The livelihood options, such as agricultural farming, seasonal fishing, and small-scale business can greatly reduce which increases the vulnerability of erosion communities.

A group of landless erosion victim people at ChanderChar expressed their views as they maintain their livelihoods working as day-labour only two-days in a week at Mahajan Bazzar; earlier all of them were agricultural labour working almost in seven days.

Income and poverty:

The identified labels for income and poverty are purchasing capacity, resettlement, shifting homestead, micro-credit support and income generation scheme. It is observed that purchasing capacity has remarkably reduced due to loss of land, homestead and change of livelihoods. The erosion affected peoples are migrating towards the

roads/embankment sides. Several times they shifted their homestead and now resettled along the road/embankment side. Inadequate micro-credit support is available especially to the women and sometimes they are unable to pay the weekly installment. Income generation scheme supported by government or non-government is totally absent. For small landowners, frequent bank erosion can decrease the returns from the working land; sometimes they become landless or even homeless.

Some of the erosion victim people who has land at ChanderChar opined that they already shifted their home three to four times which needs huge capital cost for them.

In tidal plains like Nabaganga River, saline waters and deteriorating soil quality due to saline are causing lower crop yields, thus reducing food security and earning potential of marginalized landholders. For any poor erosion victim people who depend on incomes from farming or agricultural activities or make a living as hired farm labourers, with no reserve to put them back on their feet or pay for basic needs after a severe bank erosion. They are obliged to migrate to the nearby road / embankment side or to the cities and usually drive themselves into debt. Newcomers to a city are obliged to settle in temporary dwellings in informal settlements on marginal lands near the drainage facility and are subject to frequent shifting. Moreover, they can not afford safe, expensive, economically strategic locations in the city. Such settlements with temporary structures often lack of public service utilities such as drinking water, sanitation and health facilities.

Women sufferings:

The identified labels for women sufferings are sanitation facilities, drinking water supply, taking foods, age group of women head and women headed house hold. The inadequate sanitation facilities have been observed for the resettled erosion affected community along the road/embankment side. The facilities of drinking water supply are not enough, approximately ten household getting such facilities from one tube-well. The observed specific vulnerability and impacts on women are additional stress caused by child and aged care in limited spaces; and limited availability of fuel, food and supplies. Moreover, women face loss of privacy while living along the road or embankment side or makeshift dwellings in the city with constrained facilities for sanitation. In addition, women groups can not participate to rebuild community solidarity after river bank erosion though they can share information, ideas and resources.

Additionally, Ineffective response of national / regional political leaders to mitigate the bank erosion problem may lead to public dissatisfaction in the authorities of the governments. Lack of or inadequate mitigation plan in erosion vulnerable area may cause social inequity and even social conflict. For instance, erosion victim peoples at ChanderChar demands for loop-cutting whereas government has taken up the bank protection measures. Though these bank protection measures can not protect the lands from bank erosion, it was observed during the last decades. As a result, such discrepancies and imbalanced economic growth has produced social anxieties among the people.

A group of the erosion victim people at ChanderChar thought that one loop-cut will solve their problem but the local MP is disagreeing with them apprehending his loss of land.

Erosion victim people at ChanderChar and Noagram have lack of faith in the social system and lack of confidence in political decisions to be able to manage the social conflicts itself. The present erosion mitigation measures such as retired embankment are planned and implemented without considering the indigenous knowledge of erosion victim groups. In this regard, knowledge can play an important role in creating consciousness and changing behaviour matching with time. Limitations of indigenous knowledge due to changing risk scenarios and accessibility of new options based on technological aspects under IRBEM needs to be kept in mind.

5.1.4 Social vulnerability index

Socio-economic and demographic data of erosion prone area along the bank of the Nabaganga River were used to construct an index of social vulnerability to bank erosion hazards, called the Social Vulnerability Index (SVI). Generally speaking, vulnerability to any hazards means the potential loss. Since losses vary geographically, over time and space, and among different social groups.

The vulnerability paradox

Within the hazard literatures, socially created vulnerabilities are largely ignored, mainly due to the difficulty in quantifying them. Social vulnerability is partially the product of social inequalities – those social factors that influence or shape the susceptibility of various groups to harm and that also govern their ability to respond. However, it also includes place inequalities – those characteristics of communities, such as the level of

livelihoods, growth rates and economic vitality that contribute to the social vulnerability of places. To date, there has been little research effort focused on comparing the social vulnerability of one place to another. In this research a concept of model vulnerability (see **Figure 5.1**) has been illustrated to produce erosion hazard potential interacts with erosion risk (an objective measure of likelihood) and mitigation (measures to reduce the bank erosion impact). The erosion hazard potential is either moderated or enhanced by geographic context (site and situation of the place, proximity) as well as the social bond. The social bond includes community experience with erosion hazard, and community ability to respond to, cope with, recover from and adapt to erosion hazard, which in turn are influenced by economic, demographic and housing characteristics.

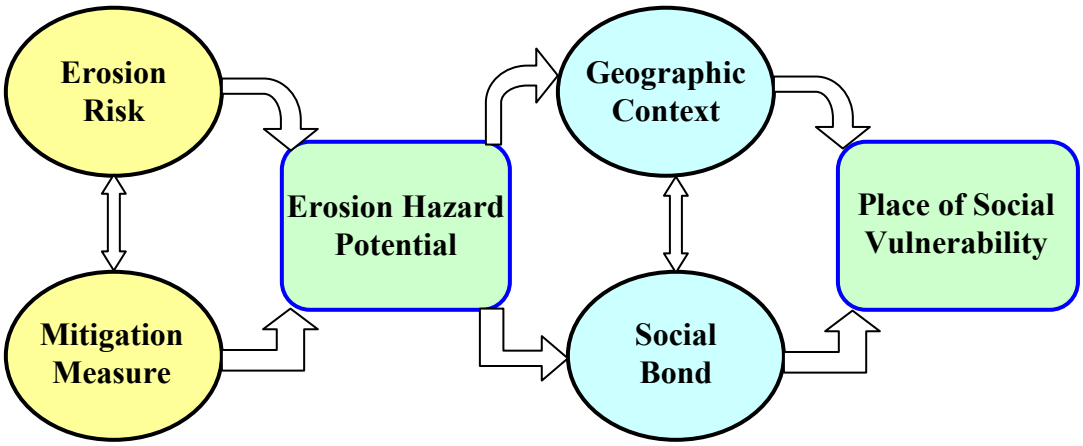


Figure 5.1: The conceptual bank erosion hazards-of-place model of vulnerability

Social indicators influencing erosion vulnerability

By analyzing the social survey data on the basis of social perception and social impact indicators consider only those characteristics that influence social vulnerability to identify social indicators in connection with river bank erosion are listed in **Table 5.2.** Other aspects of IRBEM have also been taken care of to assess the social indicators. The socio-economic impacts have been assessed depending on the magnitude of hazard (erosion rate and its extent), social perception on vulnerability condition, social impact indicators contributing bank erosion vulnerability and vulnerability of the elements at risks. All these issues have linkages in between prediction of river bank erosion rate, social perception through risk assessment and strategic economic assessment. In this regard, stakeholder participation is inevitable for combining the IRBEM principles of top-down and bottom-up approach for decision making instead of top-down approach.

Table 5.2: Social vulnerability indicators and matrices

Indicators	Description	Social vulnerability Increases (+) or Decreases (-)
Socio-economic status (income, political power, prestige)	The ability to adapt losses and enhance resilience to bank erosion hazard impacts.	Low status (-) Low income (-)
Gender	Women faces more difficult time for family care responsibilities	Gender (+)
Age	Old age spectrum affects the mobility of the affected people. Parents lose time and money for resettlement & recovery and lack of resilience	Elderly (+) Children (+)
Commercial (small-scale) development	The value, quality and density of commercial entity (local bazaar) provides an indicator of the state of economic health of the erosion affected community and potential losses in the business community	High density (+) High value (+)
Employment loss	The potential loss of employment exacerbates the number of unemployed workers in a community, agricultural labourer turns into day-labourer	Employment loss (+)
Residential property	The value, quality and density of residential construction affect potential losses and recovery. Resettlements along the erosion prone area are costly to replace; mobile homes are easily destroyed and less resilient to erosion hazard.	Mobile homes (+)
Infrastructures and lifelines	Potential erosion causes loss of roads, bridge, embankments, school, madrasha, bazaar compound which creates an insurmountable financial burden on smaller communities.	Infrastructure loss (-)
Occupation	Some occupations may be severely impacted turned into day-labourer and affected people will seek alternative employment including migration.	Agricultural (-) Labourer (+) Service sector (+)

Cont'd

Indicators	Description	Social vulnerability Increases (+) or Decreases (-)
Family structure	Families with large number of dependents or single-parent households often have limited finances to outsource care for dependents and care for family members. All affect the resilience to and recovery from erosion hazards.	High birth rates (+) Large families (+) Single-parent households (+)
Education	Education is linked to socio-economic status, with higher educational attainment resulting in greater lifetime earnings. Lower education constraints the ability to understand warning information and access to recovery information.	Primary education (+) Higher education (-)
Population growth	Erosion-prone zone experiencing rapid growth, lack of quality housing and the social services network.	Rapid growth (+)
Medical Services	No health care facilities in the erosion prone area	Medical facilities (-)
Social dependence	Those people who are dependent on social services for survival in-terms of economically and socially marginalized and require additional support in the post-erosion period.	High dependence (+)

5.2 Mechanism of Stakeholder Participation

5.2.1 Identification of stakeholder

The present bank erosion mitigation measure practiced in Bangladesh has largely been a top-driven and engineering-centered procedure. In recent years, it has been observed that cooperation and collaboration across different sectors and people participation in the development projects provides the better consensual decision. The effectiveness of IRBEM approach mainly depends on participation of key stakeholder from the start. Greater participation of all stakeholders in erosion policy development and implementation process is considered vital to choose the level of risk as inhabitants of erosion-vulnerable reaches are ready to take. In this regard, it is essential to identify the key stakeholders who should be involved in the participatory process. But too many

stakeholders can turn into the participatory process cumbersome and fruitless. For effective integrated river bank erosion management three groups of relevant stakeholders has been identified:

- Government ministries, departments and agencies;
- Bank erosion affected communities; and
- Scientific institutions – universities, research organizations.

5.2.2 Analysis of stakeholder response

The stakeholder response needs to be analyzed considering the cluster or homogeneous group of peoples. Each stakeholder groups have individual needs and requirements based on their respective roles and responsibilities. The participation methods with varying degrees of stakeholder involvement are suggested for IRBEM such as dissemination of information, public hearings through discussion, consultation through FGD including self-management, as illustrated in **Figure 5.2**.

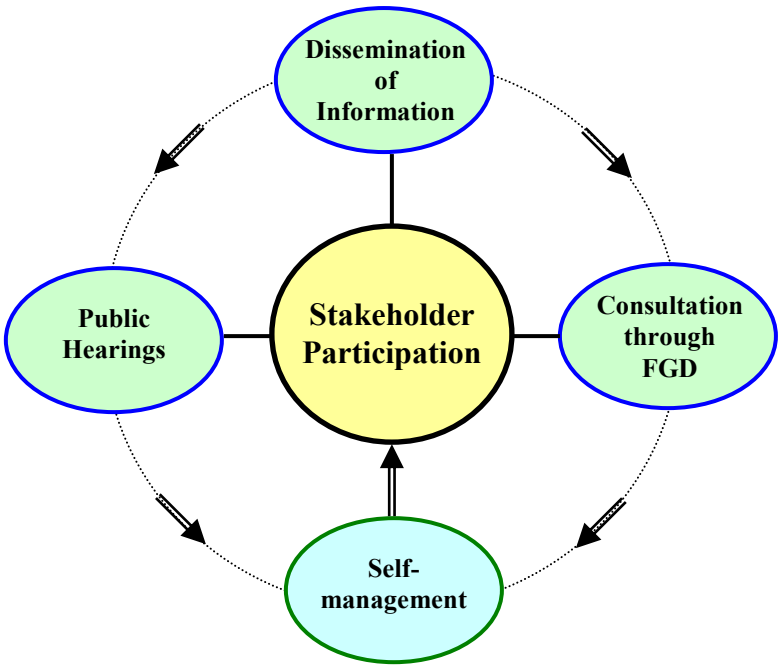


Figure 5.2: Functional mechanism of stakeholder participation

The primary level of public participation consists of the dissemination of information on decisions taken by the decision-makers on a particular erosion mitigation measure. The next level involves public hearings on those decisions when feedback and agreement are sought from the stakeholders. Consultations involve soliciting

stakeholder views on proposed action and engaging them in a dialogue. It is important to motivate the people for self-management, and then the community or individual takes its own decisions. Stakeholder participation in connection with river bank erosion is demanding and needs to be carried out through a representative method. The methods of participation to be applied at different stages of the planning process for IRBEM has been defined (see Figure 5.2).

5.2.3 Needs of stakeholder participation for IRBEM

River bank erosion management plays an important role in sustainable development. River bank erosion management activities should be carried out under a flexible but well defined approach guided by the national water policy (MoWR, 1999), national water management plan (WaRPO, 2004) and poverty reduction strategy plan (GoB, 2005) are briefly listed in **Table 5.3**, which address bank erosion next to other water sector and poverty alleviation issues. These three documents emphasized the need for integrated river bank erosion management. In line with policy documents, the planning process and how the challenge of participatory processes could be addressed at various levels of planning and implementation under IRBEM are discussed below.

Table 5.3: Bangladesh policy documents

National Water Policy (1999)	National Water Management Plan (2004)	Poverty Reduction Strategy Plan (2005)
Article 4.2: Planning and management of water resources … "*Through it responsible agencies, the Government will undertake survey and investigation of the problem of river bank 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*". …	NWMP states that river bank erosion is a major problem in all main rivers. Article 3.7.2: … clearly spell out about erosion control, river bank maintenance and recommends the approach to be followed, particularly with focus on formulating an updated strategy dealing with the problem for sustaining people's livelihoods and halting erosion. …	PRSP states the need for erosion control in many parts of the document. Article 5.B.1: Water resources and management … "*River erosion creates poverty by making people homeless overnight. The poor are affected more*."…

Local Erosion Management Association (LEMA)

The key to IRBEM is the local erosion management association (LEMA). A local erosion management plan should start with adequate erosion mitigation measure by the local need to reduce bank erosion risks, secure livelihoods, sustain economic

development and preserve environmental quality. The mitigation measure needs to be largely guided by the regional development objectives. The four step plans for LEMA participation has been identified by analyzing the field survey data/information are discussed below.

Plan-1: Ensure stakeholder participation

- Identify stakeholders and analyze the participation process;
- Initiate a public awareness campaign regarding bank erosion risks;
- Assess the required data/information with data collection methodology;

Plan-2: Assess bank erosion risk (to be presented in the hazard map)

- Generate a database inventory which includes:
  - Loss of land, property, homesteads, roads and other infrastructures;
  - Land, property, homesteads, roads and other infrastructures to be threatened;
  - All associated risk to be presented in the hazard map;
- Assess the potential bank erosion risk;
- Disseminate the risk assessment at the local level;

Plan-3: Counseling about erosion mitigation plan

- Develop mitigation measure (structural/non-structural) based on plan-2;
- Discuss the pros and cons of adopted erosion mitigation measure;
- Ensure planning process combining top-down and bottom-up approach;

Plan-4: Discussing about implementation plan

- Identify the roles and responsibility of key stakeholders during implementation process;
- Discuss about the time frame of implementation procedure;
- Discuss about monitoring, evaluation and O&M procedures;
- Disseminate the implementation plan to all stakeholders in workshop;
- Approval of the plan through workshop;

From field observations, it is revealed that the four step plans must have linkages with other management aspects (see **Figure 5.3**) to build consensus with regard to proposed mitigation plan by deciding strategies for an effective LEMA.

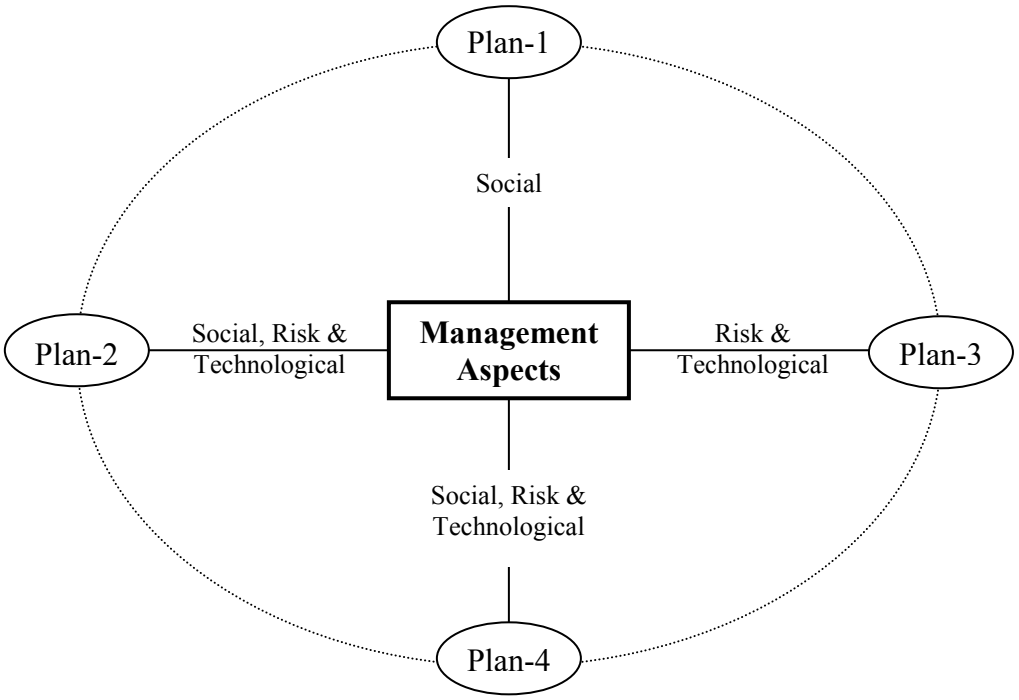


Figure 5.3: LEMA participation plan linkages with individual management aspects

Strength, Weakness, Opportunity and Threat (SWOT) analysis for stakeholder participation

IRBEM requires a comprehensive continuous approach to implement adequate mitigation measures, which could be achieved through SWOT analysis. In order to initiate the participatory process, some of the situations are highlighted below as *opportunities* as a *strength* as well as weakness as a threat to the participatory approach for building stakeholder capacity.

Strength	**Weakness**	
o Highly aware communities o Stakeholder identification and consultation o Sustainability of the project o Synergy with existing structures		**Opportunity**
	o Bank erosion risk perception o Attitude towards bank erosion management o Political will o Need for financial commitment and budget allocations	**Threat**

5.3 River Bank Erosion Management Operations

5.3.1 Pre-erosion and post-erosion management operations

After the local erosion management association (LEMA) has been formed, individual projects could be designed and implemented in accordance with the time frame established in the plan, and the availability of financial resources. The first step in project-level planning is to assess the socio-economic impacts by predicting the bank erosion rates and its extent, addressing the risk factors, employing various economic tools for making choices through multi-criteria analysis (MCA) and cost-benefit analysis (CBA). The basic data for prioritization is the outcome of the erosion risk and local needs assessment to be addressed during the local erosion planning stage.

Exposure analysis is required in designing individual projects and their implementation to secure the livelihood of the stakeholders and beneficiaries from the start. The project beneficiaries should be able to provide feedback on the project's effectiveness in order to make further improvements or requirements. In this way resilience of the erosion affected people could be enhanced by selecting suitable erosion mitigation measures. In this regard, an appropriate stakeholder mechanism needs to be built in at the project planning stage.

In Bangladesh while decision-making authority is retained by the government, interaction with people and obtaining feedback allows affected populations to influence the decision-making process by raising several issues. The common issues are stakeholder participation, detailed analysis of alternatives/options, project design, adequate erosion mitigation plan, monitoring and management plan. An action plan for each project is then developed, together with information on detailed activities, time lines and implementation plan. Local ownership and accountability may be established through public participation and proper consultation.

5.3.2 Erosion emergency management operations

An emergency plan for preparedness consists of raising public awareness and emergency preparedness plan with coordination mechanism. The rapid need assessment is a critical component to protect the key infrastructures on the basis of early erosion

warning. For effective erosion emergency management operations following sub-plans are suggested:

- Erosion early warning sub-plan;
- Erosion monitoring sub-plan;
- Public awareness sub-plan;
- Evacuation sub-plan; and
- Recovery sub-plan.

LEMA will play the key role in erosion emergency management operations with respect to erosion warning, provision of labour and equipment, evacuation, management of safe places and addressing relief camps needs. Erosion emergency plans are generally undertaken through monitoring with pre-erosion and post-erosion management operations.

5.4 Schematic Frame of Social Management Aspects

The functional relationship between outputs of this aspects and inputs of other aspects is shown **Figure 5.4**. A schematic frame of social aspects considering all functional outcome stages is illustrated in **Figure 5.5**. In this frame, social aspects has been demonstrated by establishing a functional relationship in between prediction of river bank erosion rate, livelihood security, poverty index linking to PRSP, resettlement plan. Moreover, this frame establishes an interactive approach for pre-erosion & post-erosion management operations with erosion emergency management operations by introducing the monitoring and evaluation technique.

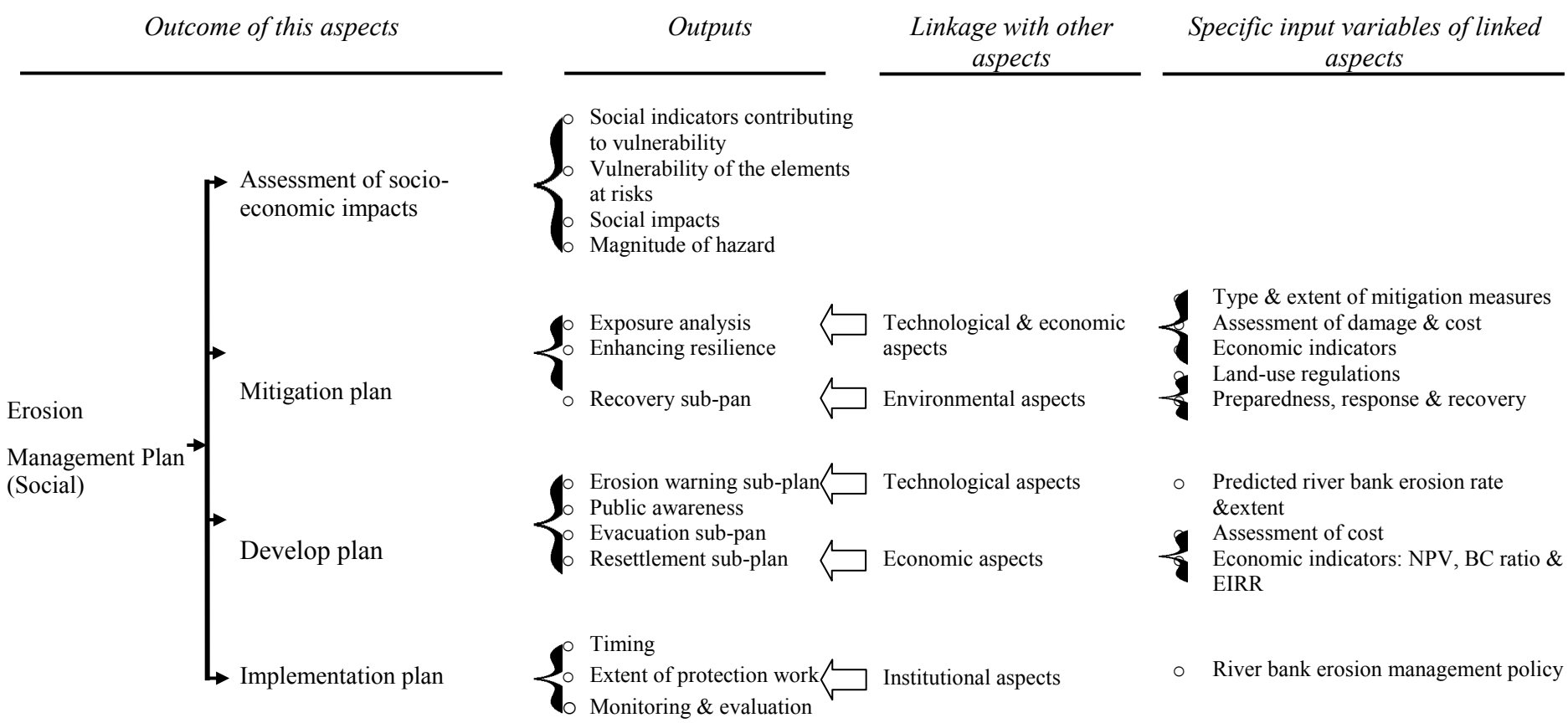
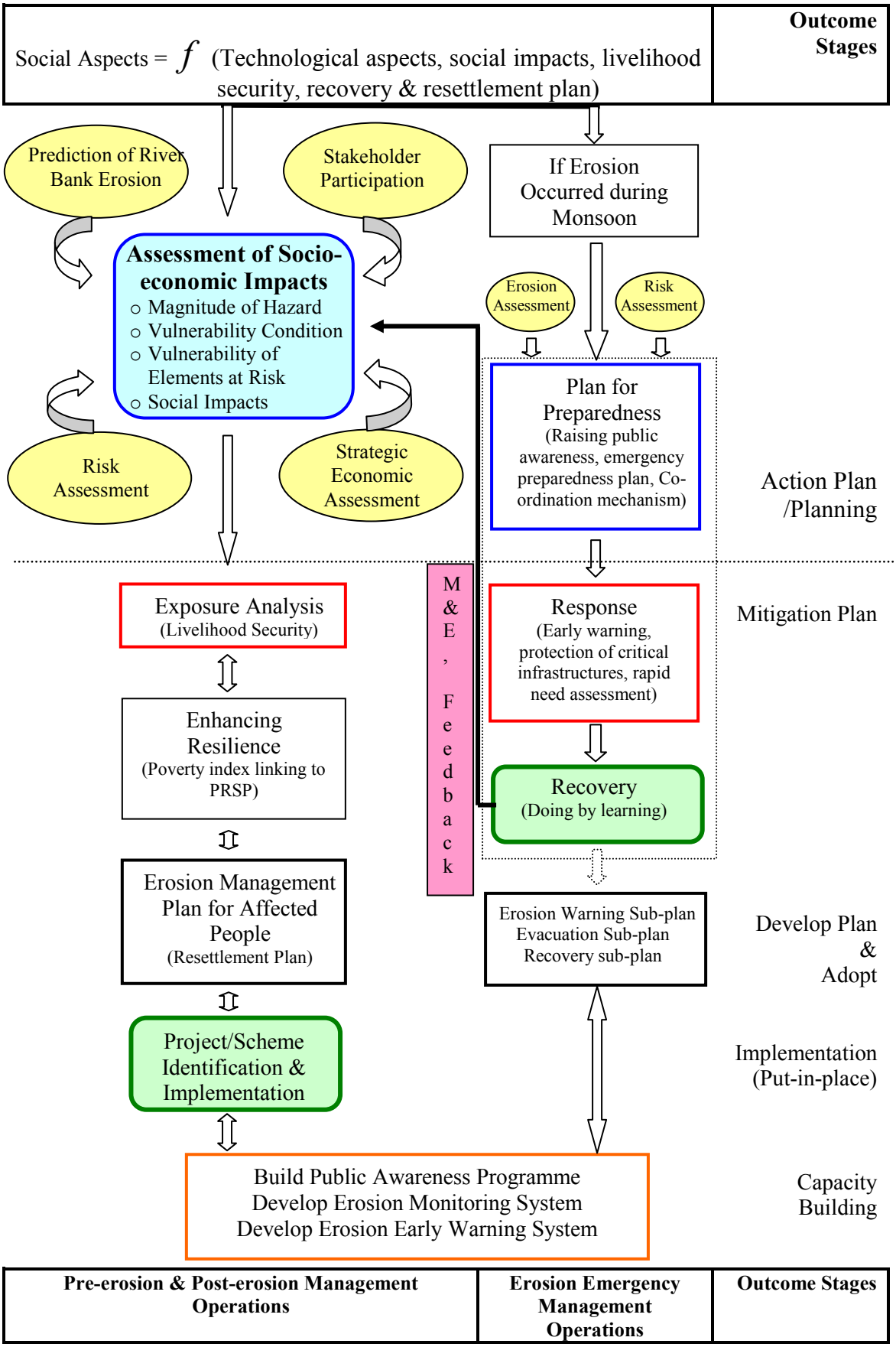


Figure 5.4: The functional relationship between input and output of independent and dependent variables

Figure 5.5: Schematic Frame of Social Management Aspects



CHAPTER SIX

RISK MANAGEMENT ASPECTS

Out of six aspects of IRBEM framework, this chapter describes the component of risk management aspects. The important features of this component are bank erosion risk perception as well as risk management which includes social exposure, emergency management in-terms of preparedness, response and recovery.

6.1 Bank Erosion Risk Perception

The consciousness of bank erosion risks is a fundamental element of societal risk observation. When the community is responsive about the forthcoming bank erosion risks, then the social vulnerability can be assessed by analyzing the social impact indicators. In IRBEM, potential bank erosion risks can judiciously be determined by predicting the future bank erosion rate and its extent. As a result, the bank erosion risk perception of a community can be assessed through erosion analysis and social impact indicators analysis.

A social conflict has been observed among the erosion victim people at ChanderChar and nearby village regarding the implementation of ongoing erosion mitigation measures along the bank of the Nabaganga River. The conflict arises based on their imaginative knowledge, which needs to be sharpened with predicted erosion rate & its extent.

Social conflicts between affected and non-affected communities generated considering their indigenous knowledge. These conflicts can be minimized, when their knowledge updated with predicted erosion rate and its extent. They can share the ideas and protect themselves based on their experience and achieved knowledge. The updated knowledge tells how much they are vulnerable due to bank erosion during monsoon. However, the community can recognize these risks through consultation with elderly inhabitants, community leaders and elites. Perception about bank erosion risks within a community can vary according to their relative educational level, economic position and political power. Similarly, responses can also vary which generates social conflicts.

6.1.1 Assessment of the bank erosion risk

IRBEM aims to reduce bank erosion risks. The risk may define as the expected losses from given erosion hazard over a specified time period. By synthesizing the field data information, following bank erosion risk perception and its reduction mechanism (see **Figure 6.1**) has been constructed which consists of:

- The magnitude & extent of the bank erosion hazard in-terms of erosion rate;
- The exposure of human activities (mitigation measure) due to bank erosion; and
- The social bank erosion vulnerability of the elements at risk;

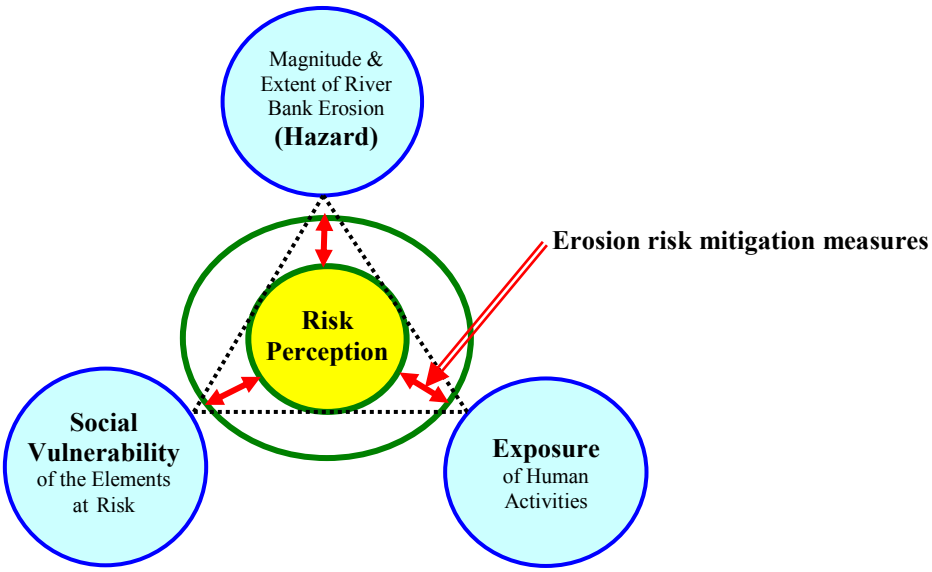


Figure 6.1: Bank erosion risk perception and its reduction mechanism

In river bank erosion, total vulnerability may be expressed by combining exposure to hazard and vulnerability of the elements at risk. In IRBEM practices, when defining bank erosion risks, a clear distinction between hazard and vulnerability needs to be essential to analyze the erosion problem. However, unique strategies can be adopted from an engineering viewpoint as well as considering social issues. A systematic bank erosion risk analysis must be carried out for building societal resilience. The analysis includes an assessment of hazards, community vulnerability and development requirements. The bank erosion risks as on IRBEM may reduce through a judicious combination of measures that address the magnitude of the hazard, exposure and vulnerability. Therefore, the bank erosion risk reduction measures must be undertaken in combination with water resources management and development activities in the

bank erosion vulnerable area. Consequently, the entire erosion vulnerable area should be undertaken as a single entity where management needs its hydrological, rather than administrative or political boundaries. Moreover, the mitigation measures need to be consciously designed to cause minimum impacts on the environment.

Bank erosion is generally a product of a complex interface between natural processes in the form of floods and near bank velocity with local geometry of the river system. The near bank velocity characteristics undergo a continuous change substantially overtime depending on the tidal floods frequency and consequently effect a change in bank erosion rates. Therefore, bank erosion management measures and development activities must be designed in such a way that may not generate any adverse impact on local flow regime.

6.1.2 Assessment of the bank erosion vulnerability

Vulnerability to bank erosion depends on community's consciousness. The incapacity of a community or a group of bank erosion affected people aggravates the situation of bank erosion vulnerability. The consciousness of such situation determines the consequences of a hazard into a disaster. After bank erosion, the severity of the adverse impact may be further exacerbated for a long time. The river bank erosion experienced from field observation reveals that situation of bank erosion vulnerability is a interlinked phenomenon of physical, managerial, and motivational approaches. As a result, the bank erosion vulnerability may be divided into these three main groups as shown in **Figure 6.2**.

Local people at ChanderChar and Noagram understand erosion vulnerability as losses of land, reducing their livelihood; lack of or limited access to political power, lack of initiatives; lack of awareness of erosion mitigation measures etc.

In addition, the risk vulnerability indicators that contribute to or influence these conditions would determine community vulnerability. The following risk vulnerability indicators relevant to bank erosion have been identified and standardization of these indicators is given in **Appendix-B**.

- Population exposure
- Land values
- Infrastructures
- Resilience
- Sources of livelihoods
- Environment
- Social support network
- Mitigation measures
- External support
- Local power

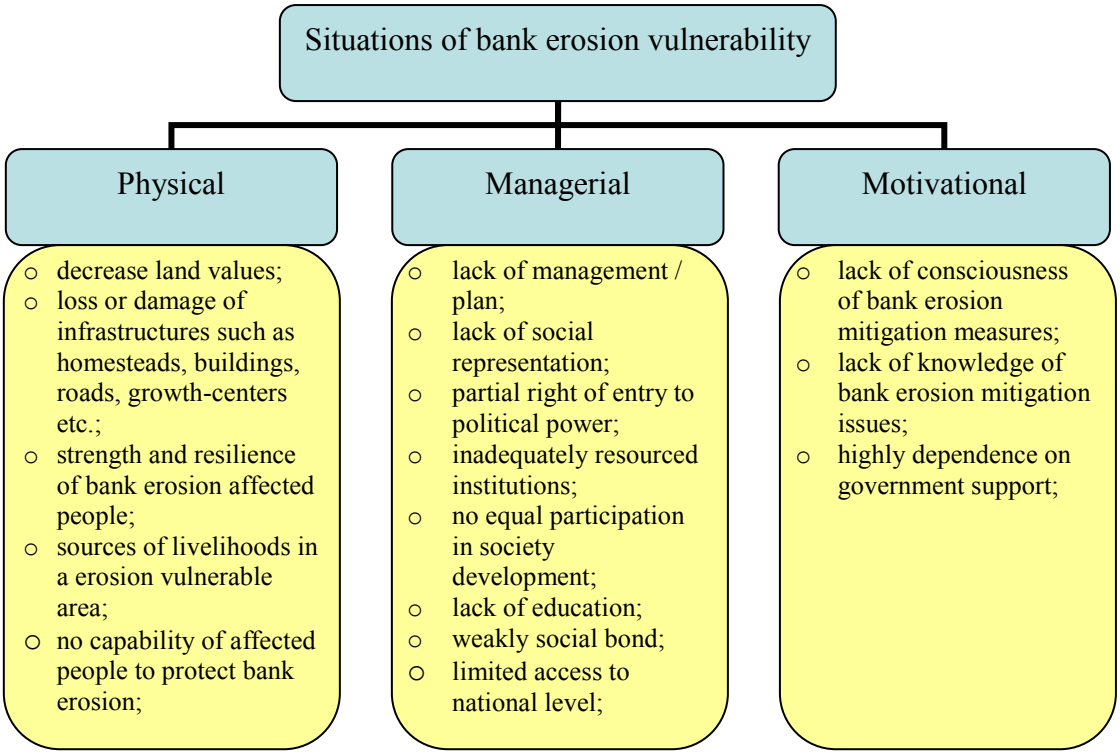


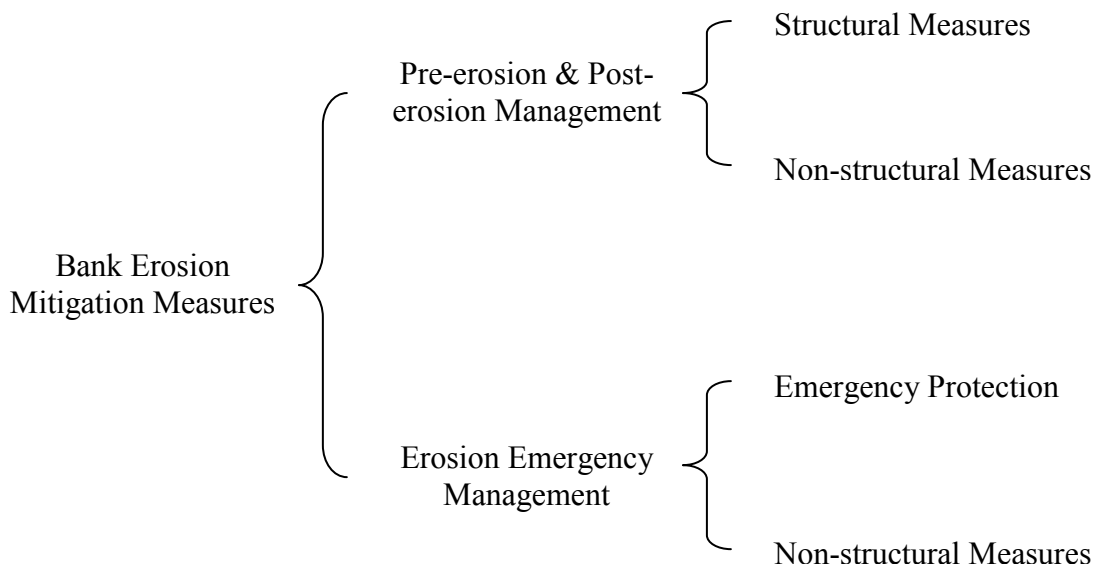
Figure 6.2: Situations of bank erosion vulnerability

The bank erosion vulnerability is determined by establishing physical, managerial and motivational situation. The complex variety of erosion vulnerability generates when these situation are reinforced with some social impact indicators such as income and poverty, loss of livelihoods and women sufferings. The usefulness of the actions to reduce vulnerabilities and to enhance social resilience can be addressed by properly identifying underlying factors:

- socio-economic factors leading to livelihoods of the erosion affected area;
- occurrence and magnitude of bank erosion rate;
- present and predicted bank erosion rate and extent;
- social vulnerability of the elements at risks; and
- estimated impacts of bank protection work.

6.2 Bank Erosion Risk Management

The following bank erosion mitigation measures can be taken up to reduce the bank erosion risks by decreasing the magnitude of erosion hazard and overcoming the vulnerability of erosion affected community.



6.2.1 Pre-erosion and post-erosion management

Structural measures include construction of revetment, spur or groyne along the eroded river bank. These measures reduce the probability of bank erosion risks. The social exposure to approaching bank erosion can be prevented through non-structural measures. The non-structural measures may include erosion early warning message, evacuation plan and erosion emergency management. Sources of livelihoods that are likely to be adversely affected due to bank erosion can be managed by erosion early warning message. Evacuation plans involves moving the probable affected people away from the bank erosion vulnerable area to avoid losses.

Local people at ChanderChar and Noagram opined that they don't have enough land to shift or migrate themselves though they understand the severity of forthcoming erosion. As a result they occupied the area belongs to road or embankment side.

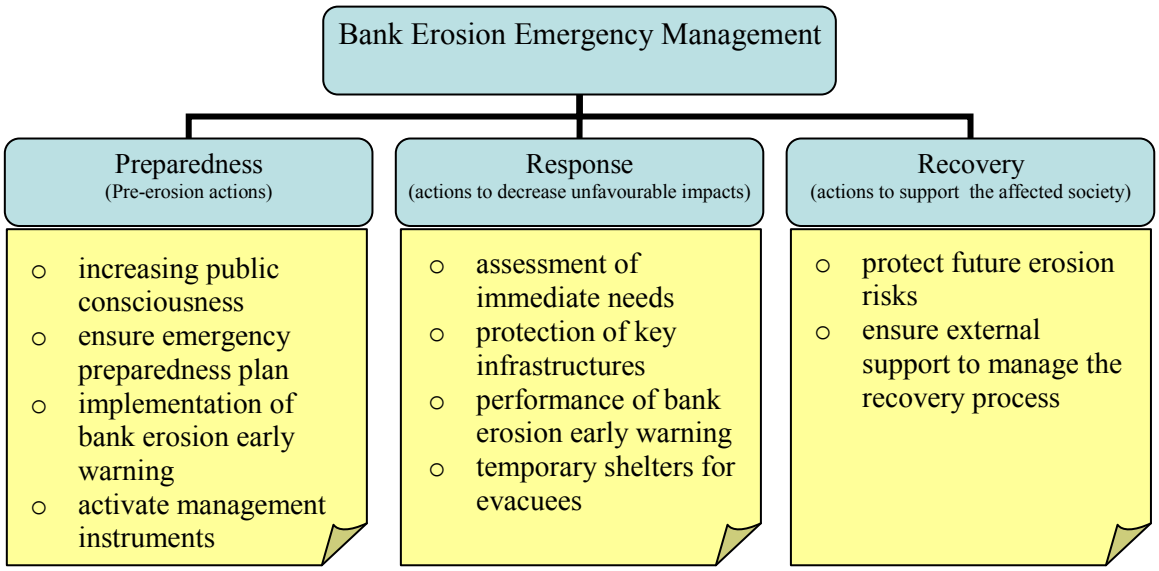
The evacuation of erosion vulnerable populations from likely eroded areas is one of the most important measures needs to be designed to adopt exposure to bank erosions, particularly when dealing with residual risks and living with bank erosions. Local authorities are best place to take a decision on when to evacuate, a perfect example of a critical decision taken in the face of uncertainty and under time pressure. Losses caused by bank erosion occur when the occurrence is not considered dangerous, time is too short to reach safe place. However, convincing the public of the likely impacts of future bank erosion of its severity is difficult, which requires awareness building. Once the

authorized organization such as LEMA has given the order to evacuate and a rescue operation needs to be undertaken to move people out of potential eroded areas on to safer ground. Evacuees should be provided with basic needs and attention given to the children/elderly/women. These operations require human financial resources supported by appropriate managerial instruments and talents.

While slow rate of bank erosion provides ample time to plan an evacuation, sudden erosion put the entire responsibility of evacuation on the individual. The LEMA can provide the information regarding alert systems about the future event through community-based erosion warning. Therefore, securing property and vacating premises during bank erosion needs to be planned in advance with erosion predictions and monitoring of erosion early warning. Evacuation plans needs to be formulated in the overall framework of erosion emergency management.

6.2.2 Bank erosion emergency management

The following bank erosion emergency management can be taken up to reduce the impact of bank erosion during emergency. The erosion emergency management strategies require standard monitoring and evaluation processes, which can practice in one year need to be incorporated into upcoming pre-erosion management operations. The bank erosion emergency management is necessary to design for managing and minimizing the damaging effects by immediate protection of lands, important infrastructures. The responsible authority must take careful attention to manage any adverse impact of ongoing or predicted bank erosion.



Some of the key components of the bank erosion emergency management operations are briefly discussed.

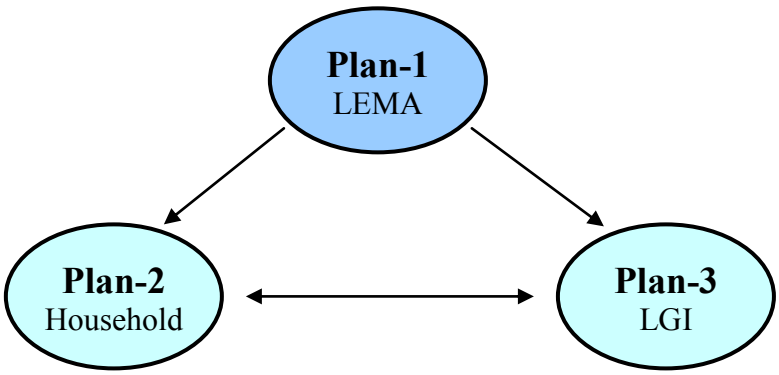
Increasing public consciousness

Consciousness and education of the bank erosion risks is the first step towards preparedness. LEMA could be organized to build resilience among the bank erosion affected community by moving them to a safe place adopting an erosion early warning plan. Consciousness could be raised through education and training, particularly in areas exposed to occasional erosion hazard or with new settlements of erosion victim people. Erosion hazard maps illustrating erosion vulnerable area, evacuating paths and protected shelters can play a vital role in consciousness building. Women, children and elder men needs special care, as they are unduly affected by erosion hazard. Sometimes their mobility may be limited or affected due to social and economic constraints.

Local people at ChanderChar and Noagram are less educated. Education and training is very much essential to build the social consciousness among the erosion victim people. Women and elderly people are less privileged.

Erosion emergency preparedness plans

The precondition for bank erosion risk reduction is increasing the capability of a community in erosion vulnerable area to respond to erosion risks. The LEMA needs to be facilitated and authorized to plan and implement their own erosion preparedness actions that will reflect local conditions and real needs of the affected people. A three step preparedness plans with their links and functional activities are described below:



Plan-1: Local erosion management association (LEMA)

- identifying safe areas for temporary shelters by LEMA;
- LEMA inform public about temporary shelters;
- LEMA coordinate all important contacts from district level to national level;

- after bank erosion, damage and needs assessment;
- setting up community volunteer team for disseminating erosion early warnings;

Plan-2: Household person

- clear understanding on the bank erosion risks;
- clear understanding about what to do when LEMA announces erosion early warning;
- clear understanding about LEMA to contact in case of erosion emergency;
- understanding of bank erosion prediction (rate and its extent);
- moving safe place as on instruction of LEMA;
- protecting valuable household items including livestock;

Plan-3: Local government institutions (UP/municipality) & BWDB

- identifying roles and responsibilities of each agency in preparedness, response and recovery;
- preparing erosion hazard map to provide information on present and future bank erosion;
- ensure basic needs for the temporary shelters;
- increase public consciousness to cope impact on bank erosion;
- training public on what to do and what not to do during erosion emergency;
- preparation to assist in emergency response to the erosion affected community;
- regular inspecting existing erosion mitigation measures such as revetment, spur/groyne;

Erosion preparedness plans needs to be effectively linked to local upazila/district administrations as well as Bangladesh Water Development Board (BWDB). Moreover, society level emergency plans needs to be properly linked to IRBEM and development issues at the erosion vulnerable area. However, there is a link in between erosion emergency planning process and pre- and post-erosion management operations.

The LEMA needs to be established for local communities in the erosion vulnerable area to meet and share emergency preparedness plans. In this way the communities can exchange their ideas and views on their common anxieties within the erosion vulnerable area. It helps to act together with sharing activities and compromising attitude.

The local people of ChanderChar and Noagram are well aware of bank erosion. However, they have conflicts on existing mitigation measures based on their indigenous knowledge.

Management instruments

Government lined agencies from local level (union parishad) to national (ministry/ parliament) levels must share bank erosion emergency responsibilities considering the

fate of erosion victim people. In Bangladesh, several agencies mandated for emergency response committee and they meet regularly. IRBEM suggests that the committee should meet at least twice in a year to identify the probable bank erosion vulnerable area and its possible mitigation measures, well before the monsoon season start, by exchanging information on their jurisdictional responsibilities. LEMA should assess the emergency temporary shelters, probable evacuees, requirements of food and health services. LEMA should review experiences after bank erosion event and learn lessons to make future changes and upgrading in existing emergency plans.

Bank erosion early warning

Bank erosion early warning is a message informing authorities/stakeholders/affected community about the awaiting danger of bank erosions. By predicting the erosion rate and extent, it can be estimated that how much area would be in danger in the forthcoming monsoon. The warning should be more useful when it has longer lead time. The effectiveness of the respondents is an important factor depends on the reliability of the warning with its confidence. Warning needs to be provided through an officially designated single authority such as LEMA and conveyed in a local language with clear, easily understandable method. The local authority can demarcate the danger line based on the predicted erosion rate as red flag for high-risk areas, pink/orange flag for moderate-risk areas and yellow flag for low-risk areas.

Assessment of immediate needs

The local authority LEMA is expected to assess the immediate needs of the affected communities. They conduct the evacuation process for the public in high-risk areas and shift them to the safe shelter. They do immediate assessment for repairing damaged infrastructures, such as embankment, roads and seek help from the national authorities. As soon as the bank erosion situation becomes critical for a particular year, a quick assessment of the latest situation should be made to verify immediate needs and information shared with local and national authorities. The main features of emergency response are the timely and efficient management based on immediate needs.

External support to manage the recovery process

The post-erosion recovery stands challenges for the government authority to protect the future bank erosion risks. External support is necessary because local capacities cannot manage the recovery process. Long-term development goals and plans should be consulted through LEMA after basic livelihoods of the erosion affected people are

restored. The recovery period should be considered as an opportunity to improve the erosion risk situation and incorporate enhanced resilience through providing safe shelters in the khas (government owned) land, rebuilding houses, provide tube-wells and sanitation facilities. Local labour and locally available materials should be used during the reconstruction process and as much as feasible to create jobs and restore their livelihoods. The well-designed recovery process reduces erosion vulnerability depending on the existing socio-economic conditions and the political situation. It is observed from the discussion with erosion victim people at ChanderChar and Noagaon, they don't like to draw cash amount as relief support. They want the relief support as in kind like cows, cattles, poultry, and pumps for agriculture, tube-wells for drinking water and building materials. Therefore, it is very much necessary to ensure the protection of the livelihood of the erosion affected community.

The erosion-affected people at Chander Char and Naogram area want relief in kind not in cash such as lands for their shelters, building materials, cows and goats to increase their livelihood, job opportunity etc.

The local people at ChanderChar and Noagram opined that they hardly received any relief during the previous bank erosion. At one time some of them are received only 5 kilo rice.

6.3 Schematic Frame of Risk Management Aspects

The functional relationship between outputs of this aspects and inputs of other aspects is shown **Figure 6.3**. A schematic framework of risk management on the basis of above features has been illustrated in **Figure 6.4**. In this frame, risk management aspects has been demonstrated by establishing a functional relationship in between prediction of river bank erosion rate, risk perception on hazard extent, social vulnerability index, risk emergency management approach etc. Moreover, this frame establishes an interactive approach for pre-erosion & post-erosion management operations with erosion emergency management operations by introducing the monitoring and evaluation technique.

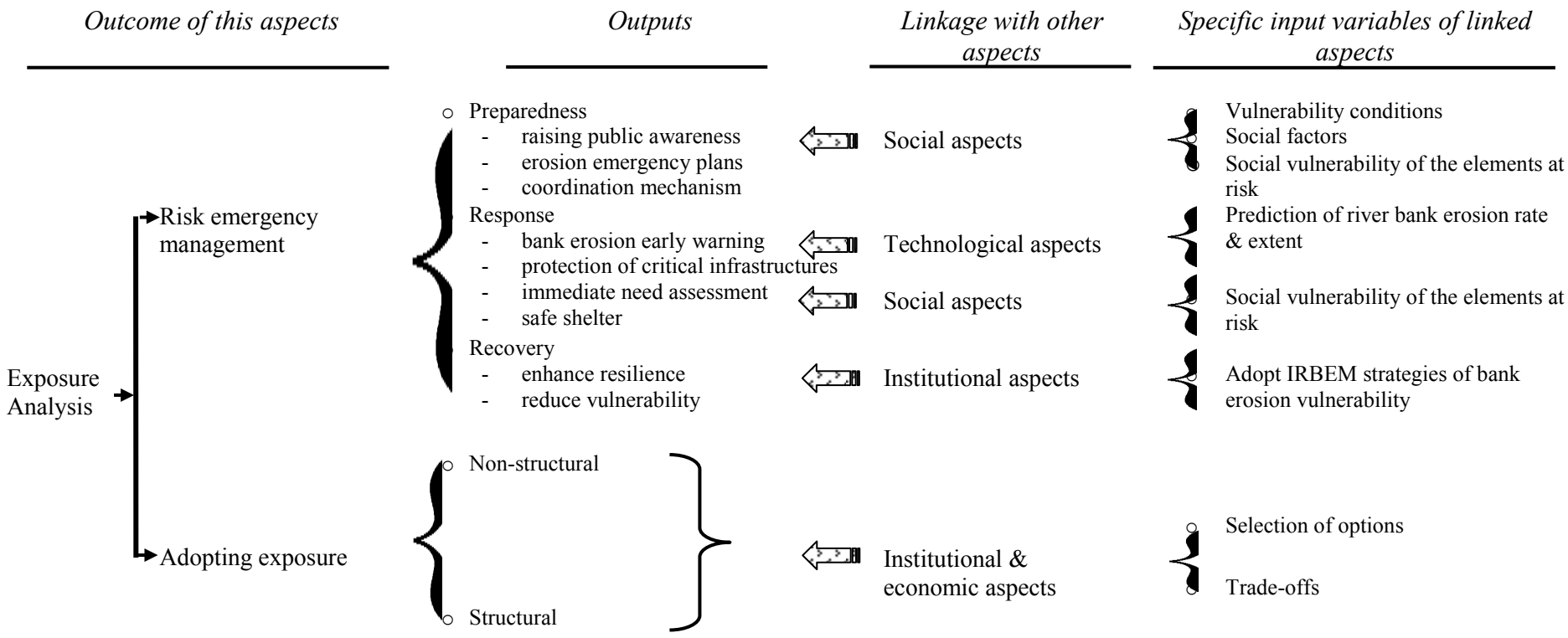
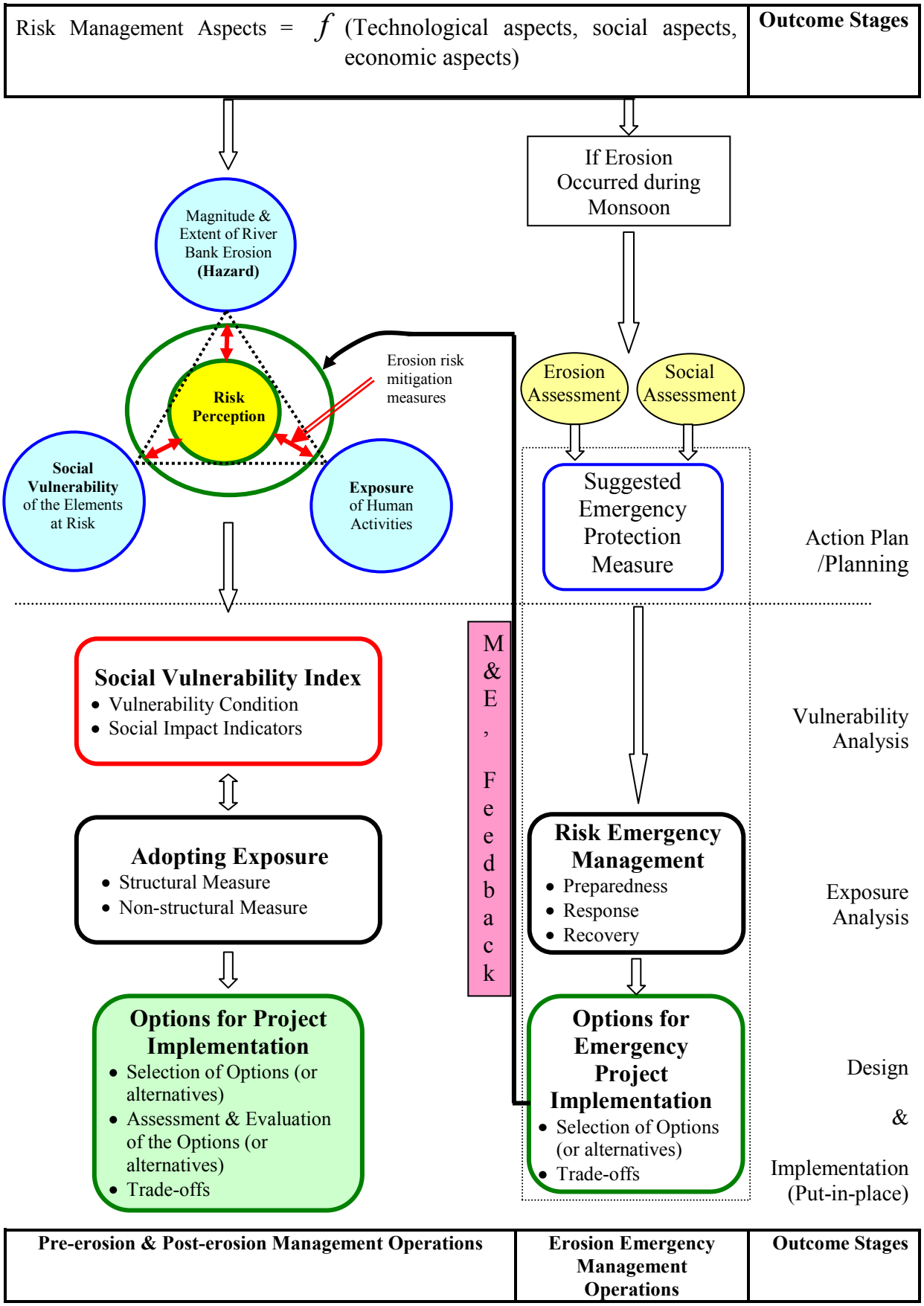


Figure 6.3: The functional relationship between input and output of independent and dependent variables

Figure 6.4: Schematic Frame of Risk Management Aspects



CHAPTER SEVEN

ENVIRONMENTAL MANAGEMENT ASPECTS

Out of six aspects of IRBEM framework, this chapter describes the component of environmental management aspects. The important features of this component are environment and ecosystems, basic concepts of the morphology and ecology of the river bank floodplains, river bank erosion management interventions and ecosystems. The environmental indicator analysis and impact analysis has been carried out by understanding the issues of this component.

7.1 Assessment of Environment and Ecosystems

The bank erosion is a natural occurrence which changes the regime of the river system. Near bank floodplain management due to bank erosion has serious consequences regarding socio-economic development of the region. The negative consequences on the environment are loss of land, people become poorer, damage of infrastructure and migration of poorer to the road/embankment side or urban slum area. Until now, bank erosion control and protection have been engineering-centered mainly relied on structural solutions i.e. embankments, revetments, spur/groin etc. These mitigation measures have changed flow regimes and separated river channels from their floodplains which have enormous impacts on biological diversity and productivity. So, any structural interventions have impacts on the natural environment and ecosystems.

In this connection, the present research looks at how environmental considerations can appropriately be incorporated in bank erosion management practices under IRBEM and discusses issues related to:

- Evaluation of bank protection processes and ecosystems for sustainable development;
- Evaluation of ecosystem services and human well-beings;
- Evaluation of hydro-morphological and ecological concepts related to river bank erosion; and
- Environmental management due to bank erosion protection measures.

7.1.1 Ecosystems and bank erosion protection processes

The bank erosion protection processes includes structural and non-structural solutions. The non-structural solution does not have any impact on natural environment and ecosystems of the floodplains. Sometimes structural solutions create environmental degradation. Therefore, during implementation of the bank protection work, the authority needs to remember the interdependency of natural resources, the environment and the development work.

In Bangladesh, the livelihoods of the near bank floodplains people depend directly on the natural resources with limited alternatives for economic growth and development. The bank protection work has been taken place at the cost of natural resources, which affected natural ecosystems and their ecological functions. Thus, present and future development must be done considering the safety of environment. Field observations reveal that degradation due to bank erosion can be stopped through integrated management of land, water and living resources. These principles have been suggested through a paradigm shift in thinking towards IRBEM.

7.1.2 Ecosystem services and human well-beings

The environment of an erosion vulnerable area can be determined by its physical setting and the river flow regimes. The various ecosystems within the environment have threatened due to river bank erosion. Sometimes, the ecosystems are resilient but if damaged fully it is difficult to restore. Therefore, it is very important to protect ecosystems of bank erosion vulnerable floodplains.

The human well-beings are surrounded by some securities such as human security, economic security, food security, health security, environmental security and political security. Environmental security means a healthy environment, when resources are managed. It is understood from field information that when natural resources are threatened due to bank erosion, human security is also threatened. As a result, people are forced to move from bank erosion vulnerable areas to marginal lands such as road side, embankment side or urban slum

Some of the peoples' at ChanderChar and Noagram already migrated to urban settlements

settlements. The major components of human security are economic security, food security, resettlement security and health security. Therefore, safe ecosystem is very important for human security with adequate reflection of environmental impacts in erosion management activities.

In Bangladesh, near bank floodplains present the best option for livelihoods, where poverty alleviation and socio-economic development are strongly dependent on the management of natural resources. In connection with river bank erosion management, the literature and field data information reveals that the ecosystem services for people include providing, regulating and cultural services that directly affect people and their supporting functions needed to maintain other social services. Many of these services are closely inter-linked with different constituents of human well-being that include security, basic needs and social bonds (see **Figure 7.1**).

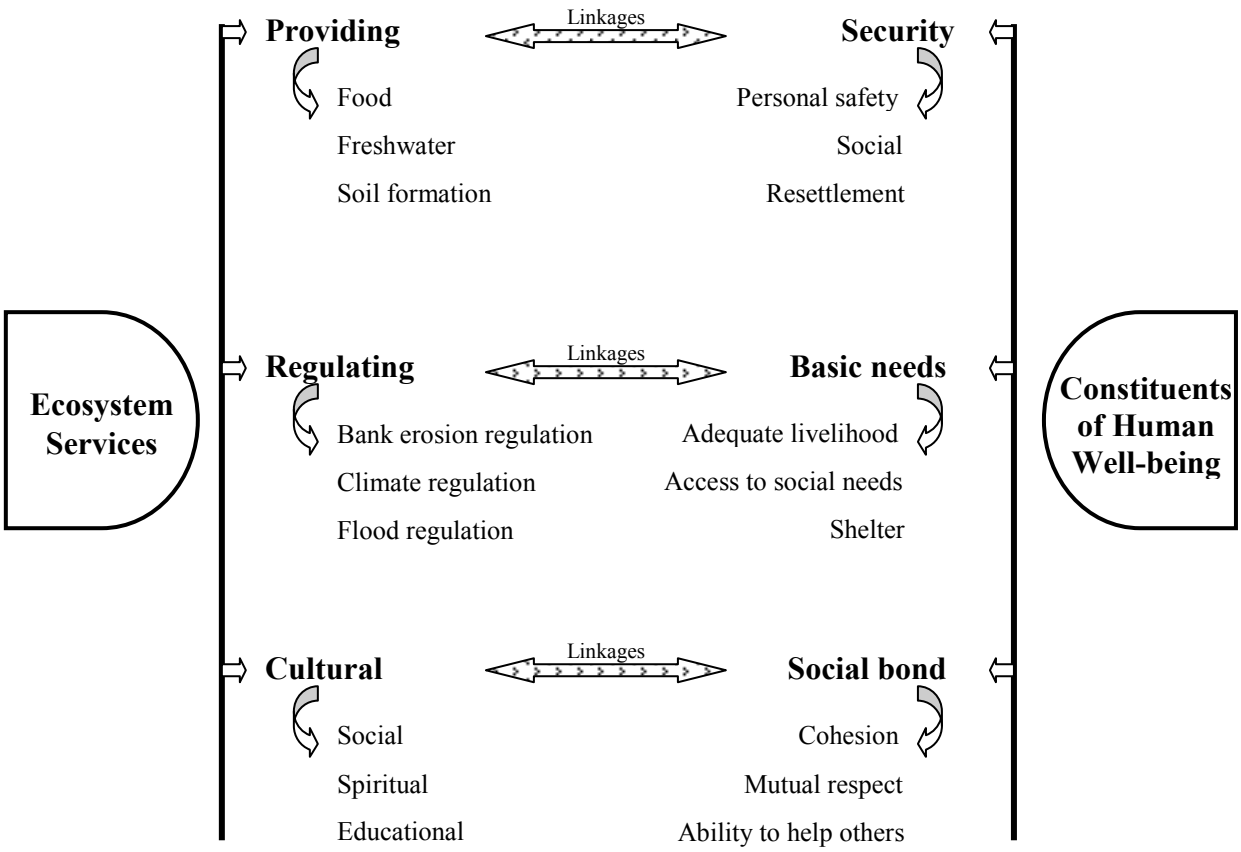


Figure 7.1: Relation between ecosystem services and river bank erosion affected human well-being

7.1.3 Features of environmental degradation

The aim of IRBEM is safety of environment through protection of river bank from erosion. As such, bank erosion management policies must designed in integration to ensure overall sustainable development. Therefore, the features of environmental degradation due to river bank erosion need to be clearly understood. It differs from place to place depending on the given socio-economic condition. The relevant features relating to bank erosion are: poverty and livelihoods, loss of agricultural land, loss of homesteads, no resettlement plan and population growth (see **Figure 7.2**).

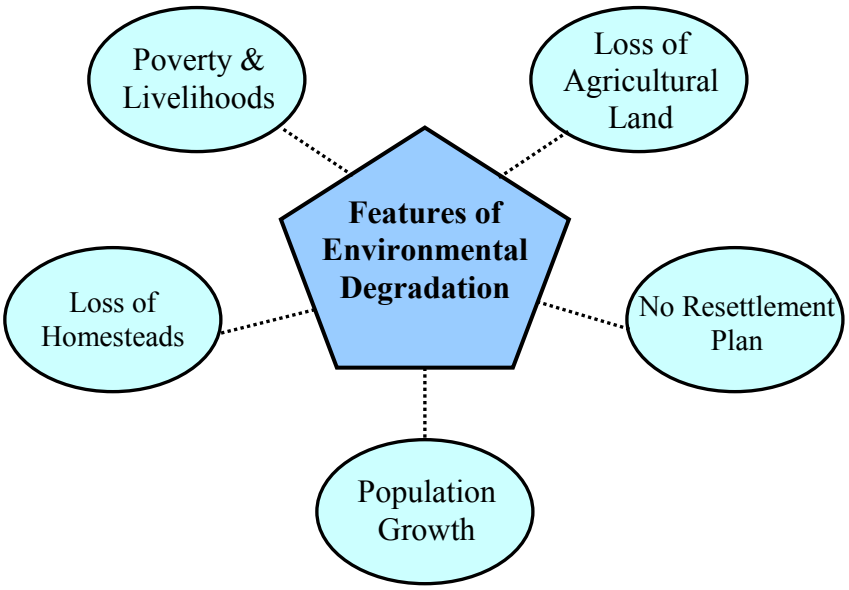


Figure 7.2: Features of environmental degradation due to river bank erosion

It is observed along the eroded bank of the Nabaganga River, exhausted natural resources and degraded environments increase the process of poverty. As a result, sometimes landless poor are migrated towards cities due to inadequate access of natural resources after bank erosion. Agriculture is the main activity along the near bank floodplain of the Nabaganga River. It reveals from field data that agricultural development disrupted due to severe bank erosion. The migrated poor people from the eroded bank of the Nabaganga River join in the urban slums of cities in Bangladesh and India due to no resettlement plan. Population growth along the bank of Nabaganga River has accelerated the impacts of poverty and livelihoods. It causes accelerated use of limited resources. Increasing population densities necessitates huge infrastructure investment to protect people, their livelihoods and property from bank erosion.

The river bank erosion management work such as embankments, revetments, spur/groin is built to meet these needs. However, if such measures are not designed correctly, they can lead to significant impacts on the environment. As a result, bank erosion management practices need to be examined within the context of environmental degradation features.

7.2 Morphology and Ecology of the River Bank Floodplains

In IRBEM procedure, how morphological and ecological processes are determined needs to know by developing the concepts of morphology and ecology of river bank floodplains. The environmental design due to bank erosion is very sensitive for mitigation measures. It facilitates understanding of the processes that determine the behaviour of rivers and their ecosystems associated with river bank erosions and floodplains.

7.2.1 Morphological processes

In Bangladesh, river bank erosion is generally occurred during flood season and floods are generated by heavy rainfall events. Flooding and bank erosion are a natural process. River channels are naturally adjusted to maintain equilibrium situation for average flow. In addition, bank erosion in the tidal plain river of the Nabaganga occurred along the outer bend of the meander part ranging from high flood to low flood when the erosive velocity take place. Flooding is the natural variation of hydrological processes. Flooding plays a key role in determining the level of natural productivity and variety of floodplains. It supplies soil fertility, habitat formation, nutrients and organisms, etc. While river bank erosion destroys the land, infrastructure, homestead etc.

The independent variables in a river basin are its geology and climate. The local temperature and rainfall systems determine the character of the soil and the type of vegetation that can grow across the basin including land use pattern. The other variables water discharge and sediment load acting through the river network are the dynamic process of morphology (see **Figure 7.3**).

7.2.2 Morphological regime with ecological connectivity

In tidal plain of Bangladesh, most river systems have alluvial form sediment bars and build a floodplain. Generally, the river landscape is determined by the interactions

among the hydrological regime (the pattern of flow variability), the sediment load, the bed and bank materials and the floodplain vegetation. Thus, the water and sediment entering an alluvial reach interact among themselves. The movable sediment boundary through erosion and deposition is adapted with the bank and bed materials and vegetation, continuously forming a range of channel patterns. Depending on its stream power or energy (a function of discharge, channel width and slope), sediment size and the effects of riverine vegetation, an alluvial channel and its associated floodplain will demonstrate meandering patterns. A clear relationship is observed between river pattern and some important ecological indicators, such as habitat density and biodiversity.

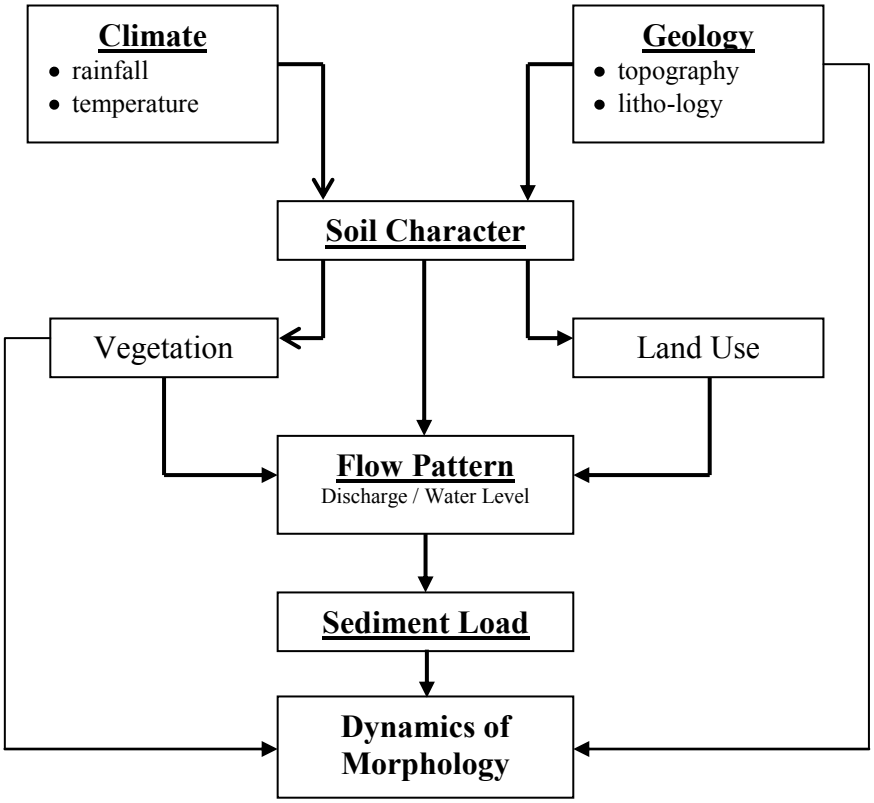


Figure 7.3: The mechanics of fluvial processes

The patterns of rivers inevitably shift around over time and create their floodplains through different mechanisms. Sometimes, the specific mechanisms of floodplain formation and the rates can vary significantly. For example, the Nabaganga River migrate laterally by eroding the existing floodplain material on the outer side of bends and at the same time depositing sediment forming point bar on the inner side, a process known as lateral accretion. Morphologically, a river can thus be considered to be in a

state of dynamic equilibrium, which means the pattern of the landform is continuously changing, but the overall composition remains the same.

The Nabganga River carries sediment to the system, erodes some parts and deposits in other parts. In addition, tidal currents and waves modify the newly deposited sediments, affecting the shape and form of the resulting plan-form. The Nabaganga river corridor results from the interaction of fluvial and hydraulic forces along the eroding vicinity of the river. The long-term evolution of a dynamic equilibrium river bed becomes a function of the rate of riverine sediment input and the rate and pattern of sediment adaptation, transport and deposition by fluvial processes after the initial deposition. Thus, a flow regime in fluvial systems influences the morphological processes of the Nabaganga River. Structural bank erosion control, such as embankments at Chanderchar and Noagram diverted and altered the flow regime and consequent sediment supply to downstream of coastal areas, thereby heavily influencing the morphological and ecological processes of these areas. Thus coastal freshwater and brackish habitats in the Nabganga River are determined by the character of the freshwater input into the system – quantity, quality and timing – and the daily and seasonal influence of tides, causing changes in salinity, temperature, turbidity and energy flux. The seasonal ebbing and flooding determine the lifestyle and agricultural practices of communities dependent on these ecosystems.

The ecological connectivity with morphology of alluvial rivers in the tidal plain and their floodplains can be summarized as follows:

- The fluvial processes always interacting with bed and bank materials. So, rivers are continuously migrating across their floodplain in the meander belt.
- The dynamic shifting of rivers and its flow pattern providing change condition for different riverine species of plants and animals.
- The riverine organisms maintain functional river ecosystem.
- The modified river regime due to bank erosion may adversely affect the fluvial ecosystems.

7.3 Mitigation Measures of Bank Erosion Management and Ecosystems

The best combination of integrated river bank erosion management approach is structural and non-structural measures. Protection of a certain area can be done by an

isolated bank erosion measures but cannot achieve the target of river bank erosion management. From the environmental viewpoint, it is important to know the influence of such measures on ecosystems.

7.3.1 Structural measures

Embankments have played a fundamental role in protecting people on floodplains against frequent flooding and recurrent river bank erosion. Embankments should be resistant to hydrostatic pressure of floods, bank erosion, piping failure and seepage. Seasonal floodplain inundation is obstructing by containing flows within embankments. This interrupts the lateral hydrological connectivity along the river corridor, with various effects on both the ecology of the channel and its floodplains.

Lack of floodplain inundation reduces transmission loss and groundwater recharge, thereby severely affecting the groundwater resources and their associated ecological and economic benefits. This has consequences on base flow-groundwater interactions, and degrades riverine habitats. Embankments reduce floodplain fertility because sediments and their nutrients are no longer deposited and exchanged. Since embankments cannot guarantee absolute flood prevention and river bank protection, they can be designed to only provide a moderate level of protection. The degree of protection is generally determined by economic considerations. Embankments that are designed for protecting Chanderchar and Noagram (see **Figure 7.4**) along the Nabaganga River need to give due weight to the environmental impacts.

ChanderChar, October 2007 Noagram, October 2007

Figure 7.4: Retired embankments for protection of the bank of Nabaganga river

No revetment, spur/groin are constructed to protect the land of ChanderChar and Noagram. However, environmental impacts of structural measures and its possible mitigation measures are given in **Table 7.1**.

Table 7.1: Environmental impacts of structural measures and possible mitigation measures

	Flow field	Impact on the environment	Possible mitigation measures
Structural measures (Embankment, revetment, spur/groin)	Flow regime	○ Increase water levels and velocities; ○ Increase flood peaks;	○ Structural mitigation measures with non-structural measures needs to be planned; ○ Spacing of spur/groin should allow morphological changes; ○ Embankment needs to design for connectivity with floodplain by setting economic and environmental criteria; ○ Structural measures needs to comply land use planning;
	Sediment transport	○ Loss of connectivity between river and floodplains; ○ Increase local erosion; ○ Increase sedimentation downstream;	
	Water quality	○ Loss of exchange of nutrients and carbon with floodplain;	
	Habitat/biodiversity /natural resources	○ Loss of floodplain spawning; ○ Loss of near bank forest; ○ No silt deposition on floodplains; ○ No more habitat creation on the floodplain;	

7.3.2 Non-structural measures

Structural measures can never absolutely get rid of the risk of bank erosion. However, they have the potential to create a false sense of security, leading to unsuitable land use in the protected areas because of their physical presence. Non-structural measures play an important role in reducing not only the disastrous consequences of residual risks, but also adverse impacts on the environment.

Erosion prediction and warning:
Erosion prediction and warning would be the accepted option to be used in future as the non-structural measures. Erosion prediction involves estimating when erosion is likely to cause damage or loss of land, what its magnitude will be (usually in terms of erosion rate at a given location) and how long its extent. Bank erosion predictions are formulated and can be issued with a certain lead time, allowing concerned authorities to take preventive and emergency measures. Authorities can respond appropriately with evacuation and resettlement plan etc. The effectiveness of bank erosion prediction and warning system is as much a function of the accuracy, timeliness and outreach of the prediction as of the response behaviour and preparedness.

Emergency preparedness, response and recovery:
The awareness of the community at risk of bank erosion should be raised and maintained, with a clear understanding of their role in responding to emergency

situations appropriately. The most important element in bank erosion damage reduction is emergency preparedness and response. This is critical in organizing coordinated evacuation from the erosion affected area and maintaining healthy and hygienic conditions. Emergency erosion measures should be available, to all concerned, well in advance by informing on evacuation paths, identifying emergency shelters and other actions. The concepts of "living with controlled erosions", rather than fighting them with structural and non-structural measures, is the most effective way of preserving ecosystems.

The following issues need to be addressed to maintain river ecosystem health by mitigating adverse environmental impacts:

- Several erosion management measures have the potential to cause consequential hydrological, morphological and environmental impacts, including impacts on socio-economic development;
- Non-structural erosion management measures have limited environmental consequences and should be actively considered as viable options such as land use regulations; erosion prediction and warning; and hazard prevention, preparedness and response mechanisms.

7.3.3 Environmental management

Each river is different in their characteristics. The nature of bank erosion will change depending bed topography, river bank and bed material, flow patterns and hydrology. From the environmental viewpoint, following concepts needs to be recognized:

- A study needs to establish the physical behavior of natural river system; so that the potential impacts of river bank protection work could be understood;
- A balanced approach to river bank erosion project is needed considering all assets and liabilities providing equal weight to environmental values;
- Preference must be given to erosion protection that minimize environmental degradation and maximize the benefits.

The Guidelines of the Government of Bangladesh, including the "Guidelines for Environmental Impact Assessment (EIA)", prepared by ISPAN [FPCO, 1992] and subsequently other guidelines suggested by WaRPO and GoB needs to be consulted for

the environmental impact assessment. The important environmental component (IECs) in a "without project" situation needs to be compared to a "with project" situation. The identified IECs relevant with risk management of river bank erosion mainly are given in **Figure 7.5**.

On the basis of defined IECs, different alternatives with and without project needs to be evaluated and compared using a multi-criteria analysis that summarizes social, environmental and economic consequences. The basic philosophy behind this evaluation is to address the adverse impacts as a result of such construction and rehabilitation activities are minimized. In order to achieve this objective all negative impacts have to be identified and mitigated during design and construction.

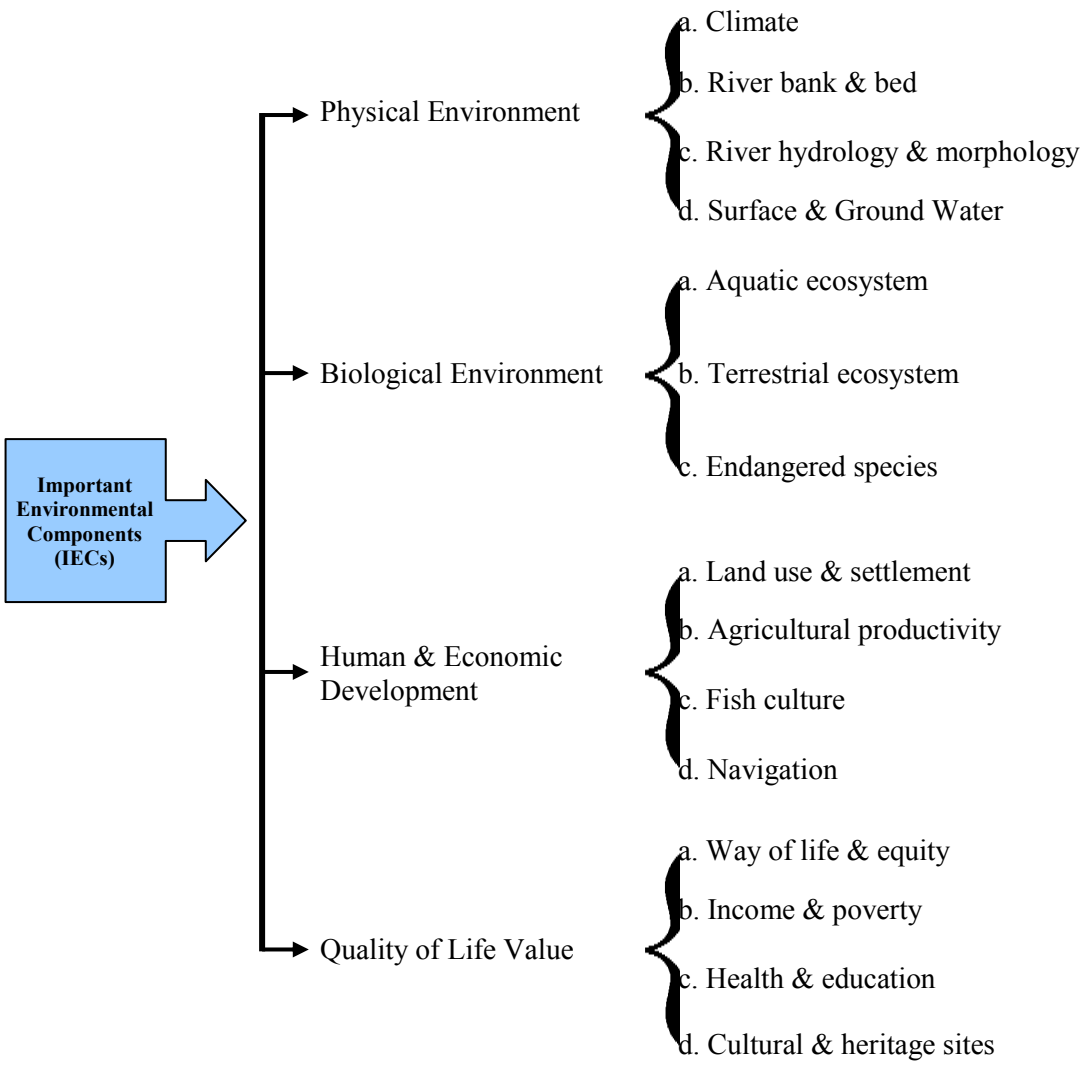


Figure 7.5: The identified IECs relevant with river bank erosion

7.4 Schematic Frame of Environmental Management Aspects

The goal of IRBEM is to maximize the net benefits from floodplains, to reduce river bank erosion risks and to minimize loss of land due to erosion in a sustainable manner. The need for a paradigm shift in thinking from erosion control to erosion management is the catalyst behind the concept of IRBEM. It integrates land and water resources management in the erosion vulnerable reach. Integrated erosion management adopts a threefold approach of i) avoiding, ii) reducing and iii) mitigating adverse environmental impacts without compromising on erosion management objectives. It is desirable to minimize the negative impacts of erosion management interventions that limit natural productivity, ecosystem health and services provided by the ecosystem, including erosion alleviation processes to a reasonable practical level. The functional relationship between outputs of this aspects and inputs of other aspects is shown **Figure 7.6**. This section provides a framework (see **Figure 7.7**) for factoring environmental considerations into the decision-making processes at various levels: action plan (planning), indicator analysis, impact analysis, project design and implementation including monitoring and evaluation, together with other relevant aspects such as legal and institutional, social and economic aspects.

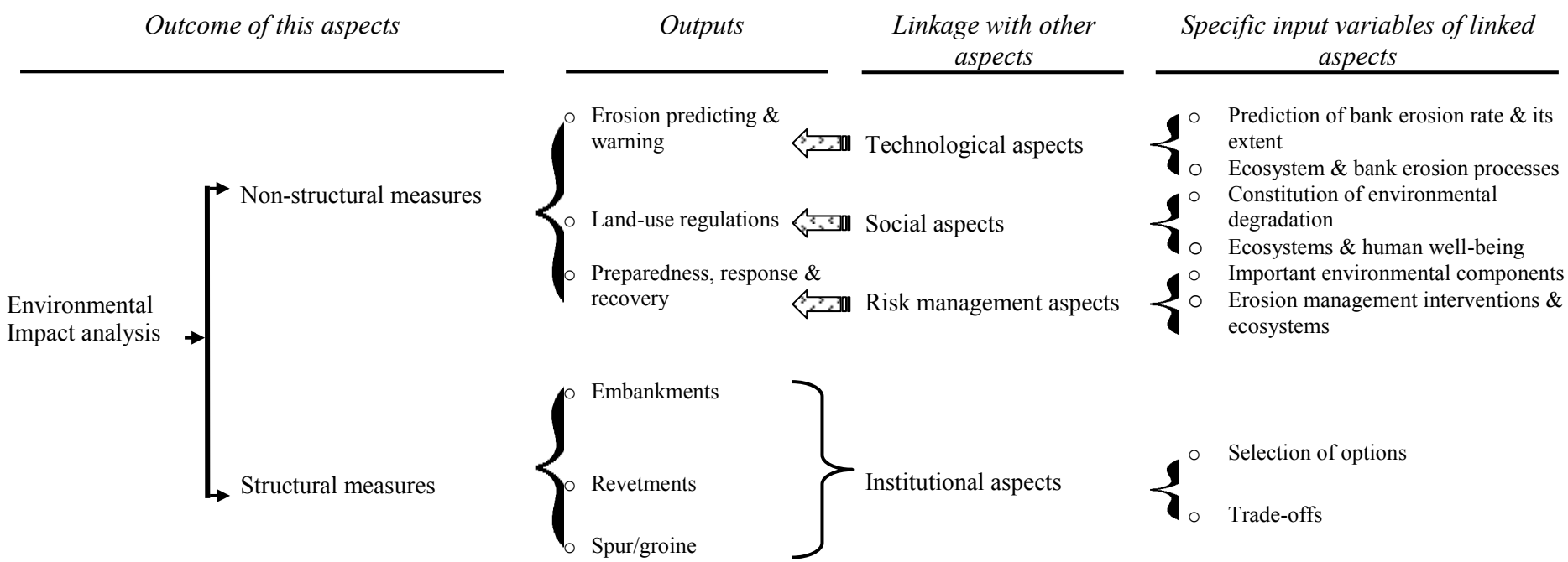
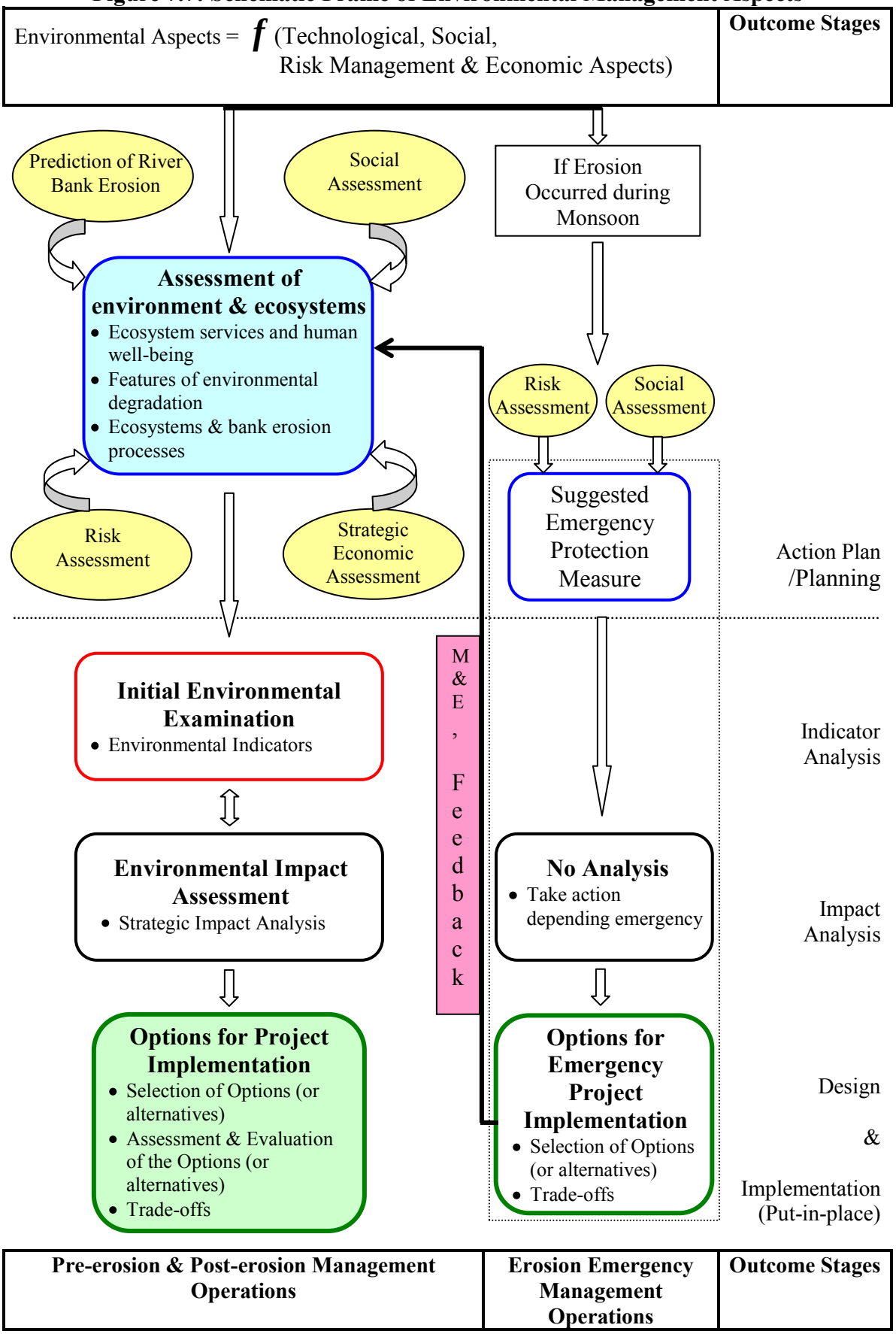


Figure 7.6: The functional relationship between input and output of independent and dependent variables

Figure 7.7: Schematic Frame of Environmental Management Aspects



CHAPTER EIGHT

ECONOMIC MANAGEMENT ASPECTS

Out of six aspects of IRBEM framework, this chapter describes the component of economic management aspects. The main purpose of economic aspects is addressed to professional engineers and administrators responsible for bank erosion management. This includes an exposition of the basic economic concepts which facilitate understanding of the economic aspects of bank erosion issues. Valuation of benefits and costs of a project in monetary terms occupies a key position in economic analysis for decision-making and priority setting related to projects. Cost-benefit analysis (CBA) forms the centre-piece of all economic analysis in the context of erosion management. Tools and techniques used for the valuation of benefits are discussed adequately including the limitations of economic analysis. The ideas, approaches and techniques discussed in this section form part of the literature developed by economists around the world. The approaches and techniques, however, have been formulated and discussed in the context of IRBEM. Hence, the language used and the style of presentation adopted is made accessible to non-economist professionals also. IRBEM promotes a dialogue among professionals from various disciplines, coming from different paradigms, to explore, among others, shared perceptions and common goals. These disciplines include public administration, agriculture, sociology, ecology, hydrology/hydraulics, morphology, river engineering and economics.

8.1 Economic Analysis of Eroded River Bank Floodplains

Land and water considers as a single component in an integrated river bank erosion management. The integration aims at minimizing the losses of land and livelihood from bank erosion while maximizing the net benefits derived from floodplains. The net benefits are the overall benefit of a society derives from floodplains uses minus the overall cost of using the floodplains (see **Table 8.1**). Assessing the net benefits from river bank floodplains involves understanding the social, economic and environmental dimensions of bank erosion risks. It requires a trade-off between development potential and the societal risks has to take in occupying floodplains.

Table 8.1: Assessment of net-benefits in eroded river bank floodplains				
Net benefit	=	Floodplain uses Agricultural output, employment, occupation, trade, business etc.	-	Overall cost of using floodplains Bank erosion damages, cost of river bank protection, resettlement of habitat etc.

8.1.1 Economic management of river bank erosion

Economic management of river bank erosion is key element to formulate the project is viable. A combination of the social impact assessment (SIA) and environmental impact assessment (EIA) is very much essential to determine how much the government would be willing to pay for reducing bank erosion risks. However, awareness of bank erosion risks varies among people depending on their geographical location. They differ widely between people living within the floodplains and those living along the eroded vulnerable area. Even the understanding of planners and the people living in the eroded river bank floodplains tend to be quite different. As a result, the way of people accepts a particular strategy of erosion management is largely guided by the awareness of bank erosion risk. The degree of erosion protection management measures are required to determines the economic viability of projects.

It is seen during field campaign at Chanderchar and Noagram, people living in poorer circumstances (lower income, educational level, social status) are unlikely to be able to express their preferences in monetary terms due to their economic, educational, political and technological constraints. Also, their preference will be given less monetary value because of their low income levels compared with their rich counterparts.

In addition, various economic constraints in management process (see **Figure 8.1**) need to be tackled through economic analysis with little or no attention to social and environmental concerns. Some of the economic choices are difficult because they arise from conflict of physical, social and environmental issues. As a result, economic analysis is a fundamental part of the policy formulation in bank erosion management. The economic analysis needs the evaluation of benefits and costs of specific bank erosion management project. Economic analysis helps to select not only the suitable protective measure to bank erosions on the basis of risk-safety trade-off decisions but also an optimum combination of structural and non-structural measures.

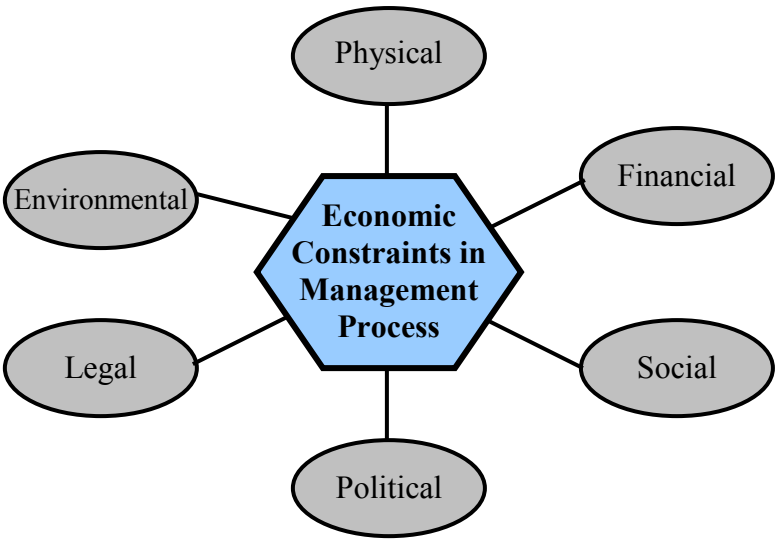


Figure 8.1: Various economic constraints in management processes

8.1.2 Evaluation of benefits

The net benefits from erosion management projects need to be evaluated from the protection of erosion damage. This is determined by the annual average of erosion damage minus the residual damage that may continue to take place even after the implementation of the erosion management project. Assessment of benefits can be drawn in monetary terms by averaging the erosion damage from the past and predicted annual average damage data (see **Table 8.2**).

Preferably weighted average damages can be obtained based on the damage-frequency curve obtained from real erosion damage records and their related frequencies (see **Figure 8.2**). Generally, in Bangladesh, erosion protection projects are usually taken up in the aftermath of severe bank erosion. Sometimes, the damage data only from such severe erosion are available. In some cases the number of years taken into account for determining the average damage varies from two to five recent years along with the erosion of the exceptional year.

The value of damage needs to be assessed for current situation based on the predictions of erosion rates and its extent. No precise methods, however, are available for assessing real damages and no general guidelines can be prescribed. However, an assessment procedure based on field data information has been illustrated in **Table 8.2**. The other benefits may evaluate by introducing early erosion prediction system both for avoiding

disturbance to business, transport networks, public services and for avoiding the costs of emergency response and recovery.

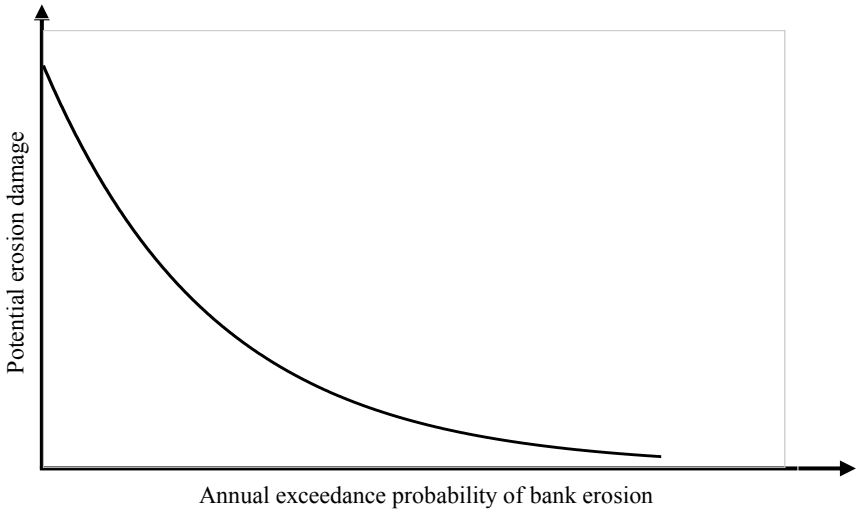


Figure 8.2: Damage frequency curve

Table 8.2: Assessment of real erosion damage data

Item	Unit	Rate	Amount
A. Past annual average erosion damage data: (Unit area approach) Value of eroded land Value of individuals properties/assets - domestic premises, - commercial premises, - retail & industrial premises Value of infrastructure damages (building, school, college, mosque, road, electric poll etc.) Value of agricultural land including crops Value of drop out children's education Value of income disruption Resettlement value			
B. Predicted annual average erosion damage data based on prediction of bank erosion area (from Technological Aspect): (Unit area approach) Value of predicted eroded land Value of individuals properties/assets to be eroded damage data - domestic premises, - commercial premises, - retail & industrial premises Value of infrastructure damages (building, school, college, mosque, road, electric poll etc.) Value of agricultural land including crops Value of drop out children's education Value of income disruption Resettlement value : (Percentage of property value approach) Value of remaining property in erosion risk zone Goodwill value for commercial entity			

8.1.3 Evaluation of Costs

A cost estimating method for river bank erosion management project needs to proceed step-by-step from the beginning to the end of the activity process of the project and accordingly identify the cost components of each step. A schematic representation of these steps, in the form of a flow chart (see **Figure 8.3**) describing the operations performed at each step, helps in giving a definite shape to the underlying cost elements.

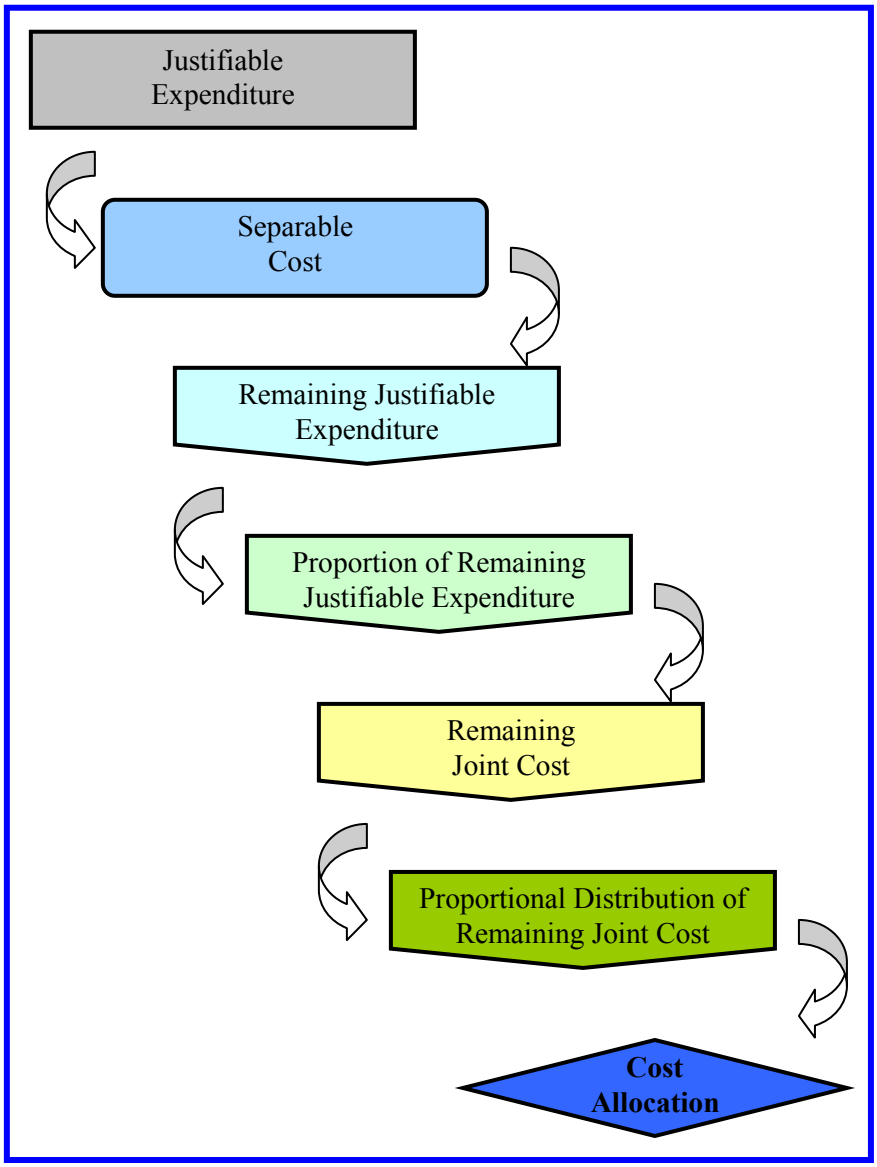


Figure 8.3: A schematic representation of the step of cost estimation component

A feature of CBA (cost-benefit analysis) becomes much more important in the context of IRBEM where a holistic approach, covering several types of objectives, is adopted. In this connection, alternative justifiable expenditure method (used by the Damador Vally Corporation Act of 1948) can be used for multi-purpose objectives. Alternative

costs are the costs of the most economical single purpose project, which can provide the same benefit, and in the same area as the multi-purpose objectives.

The above principles are taken care of by following the method of "separable costs remaining benefits method" [World Bank, 2005]. As the name suggests, separable costs, which can be separately attributed to any particular objective, are born by that objective itself. It is only the remaining costs, which are considered joint costs that are to be shared by all the objectives. The cost estimation following seven steps as on **Figure 8.3** is explained in **Table 8.3** in modified way for IRBEM.

In this connection, a multi-purpose river bank erosion management project can be planned as an example for river bank protection, resettlement issues, infrastructural development, agricultural development, income generation and safeguarding individual assets. The calculation procedure following the seven steps is given in **Table 8.3**.

Table 8.3: Seven steps for cost estimation of river bank erosion management

Step-1:	**Justifiable expenditure** Justifiable expenditure for each objective is calculated as the lesser of (a) the benefits from each objective and (b) the alternative costs of each objective.
Step-2:	**Separable Cost** Separable cost is calculated as the extra cost increased by the participation of a particular objective.
Step-3:	**Remaining justifiable expenditure** Each separable cost (step-2) is subtracted from justifiable expenditure (step-1) to obtain the remaining justifiable expenditure for each objective.
Step-4:	**Proportion of remaining justifiable expenditure** Proportion of remaining justifiable expenditure among each of the objectives is worked out.
Step-5:	**Remaining joint costs** The total of separable costs for all uses is subtracted from the total cost of mitigation measures to obtain the remaining joint costs.
Step-6:	**Proportional distribution of remaining joint costs** Remaining joint costs are distributed as per proportional distribution of the remaining justifiable expenditure for each objective (step-4).
Step-7:	**Costs allocation** Finally, the distributed costs (step-6) are added to the separable costs (step-2) to obtain costs allocated to each objective.

Step-1: Justifiable expenditure

- Justifiable expenditure for river bank protection : JE_1

- Justifiable expenditure for resettlement issues : JE_2
- Justifiable expenditure for infrastructural development : JE_3
- Justifiable expenditure for agricultural development : JE_4
- Justifiable expenditure for income generation : JE_5
- Justifiable expenditure for safeguarding individual assets : JE_6

Step-2: Separable costs

(TC: Total cost of river bank erosion management for river bank protection, resettlement issues, infrastructural development, agricultural development, income generation and safeguarding individual assets)

- Separable costs for river bank protection (SC_1):
  SC_1 = TC – (cost of bank erosion management for resettlement issues, infrastructural development, agricultural development, income generation and safeguarding individual assets)

- Separable costs for resettlement issues (SC_2):
  SC_2 = TC – (cost of bank erosion management for river bank protection, infrastructural development, agricultural development, income generation and safeguarding individual assets)

- Separable costs for infrastructural development (SC_3):
  SC_3 = TC - (cost of bank erosion management for river bank protection, resettlement issues, agricultural development, income generation and safeguarding individual assets)

- Separable costs for agricultural development (SC_4):
  SC_4 = TC - (cost of bank erosion management for river bank protection, resettlement issues, infrastructural development, income generation and safeguarding individual assets)

- Separable costs for income generation (SC_5):
  SC_5 = TC - (cost of bank erosion management for river bank protection, resettlement issues, infrastructural development, agricultural development and safeguarding individual assets)

- Separable costs for safeguarding individual assets (SC_6):

SC_6 = TC - (cost of bank erosion management for river bank protection, resettlement issues, infrastructural development, agricultural development and income generation)

Step-3: Remaining justifiable expenditure

- Remaining justifiable expenditure for river bank protection : $RJE_1 = JE_1 - SC_1$
- Remaining justifiable expenditure for resettlement issues : $RJE_2 = JE_2 - SC_2$
- Remaining justifiable expenditure for infrastructural development : $RJE_3 = JE_3 - SC_3$
- Remaining justifiable expenditure for agricultural development : $RJE_4 = JE_4 - SC_4$
- Remaining justifiable expenditure for income generation : $RJE_5 = JE_5 - SC_5$
- Remaining justifiable expenditure for safeguarding individual assets: $RJE_6 = JE_6 - SC_6$

Step-4: Proportion of remaining justifiable expenditure

$RJE_1 : RJE_2 : RJE_3 : RJE_4 : RJE_5 : RJE_6$

Step-5: Remaining joint costs

Remaining joint costs: $RJC = TC - (SC_1 + SC_2 + SC_3 + SC_4 + SC_5 + SC_6)$

Step-6: Proportional distribution of remaining joint costs

- Proportional distribution of remaining justifiable expenditure for river bank protection:

$$RJC_1 = RJC.\frac{RJE_1}{RJE_1 + RJE_2 + RJE_3 + RJE_4 + RJE_5 + RJE_6}$$

- Proportional distribution of remaining justifiable expenditure for resettlement issues:

$$RJC_2 = RJC.\frac{RJE_2}{RJE_1 + RJE_2 + RJE_3 + RJE_4 + RJE_5 + RJE_6}$$

- Proportional distribution of remaining justifiable expenditure for infrastructural development:

$$RJC_3 = RJC.\frac{RJE_3}{RJE_1 + RJE_2 + RJE_3 + RJE_4 + RJE_5 + RJE_6}$$

- Proportional distribution of remaining justifiable expenditure for agricultural development:

$$RJC_4 = RJC.\frac{RJE_4}{RJE_1 + RJE_2 + RJE_3 + RJE_4 + RJE_5 + RJE_6}$$

- Proportional distribution of remaining justifiable expenditure for income generation:

$$RJC_5 = RJC.\frac{RJE_5}{RJE_1 + RJE_2 + RJE_3 + RJE_4 + RJE_5 + RJE_6}$$

- Proportional distribution of remaining justifiable expenditure for safeguarding individual assets:

$$RJC_6 = RJC.\frac{RJE_6}{RJE_1 + RJE_2 + RJE_3 + RJE_4 + RJE_5 + RJE_6}$$

Step-7: Costs allocation

Cost allocated to river bank protection	:	Cost (bank protection) = $SC_1 + RJC_1$
Cost allocated to resettlement issues	:	Cost (resettlement) = $SC_2 + RJC_2$
Cost allocated to infrastructural development	:	Cost (infrastructure) = $SC_3 + RJC_3$
Cost allocated to agricultural development	:	Cost (agriculture) = $SC_4 + RJC_4$
Cost allocated to income generation	:	Cost (income) = $SC_5 + RJC_5$
Cost allocated to safeguarding individual assets	:	Cost (assets) = $SC_6 + RJC_6$

Integrated River Bank Erosion Management (IRBEM) involves various options for mitigating risks to life and property. Eroded river bank floodplain regulation, erosion prediction and warning, emergency response and rehabilitation are some of them. In certain cases the people at risk may adopt resettlement measures by themselves in shifting their houses in a suitable location, i.e. by migrating towards khas lands, or slum area in a town or purchasing some lands nearby town. The expenditure involved in adopting these measures should form part of the costs of the strategy selected to manage erosion in a given area.

8.2 Economic Instruments

8.2.1 Methods of assessing alternatives

The three indicators are the key parameters for economic viability analysis of bank erosion management projects, namely, net present value (NPV), BC ratio and internal rate of return (IRR). Discounting method is a best choice to evaluate the indicators. The meaning of discounting lies in re-computing cost and benefits figures of different years with a given interest rate to get their equivalent present day amounts. Calculation procedure of these indicators can be seen in any reference book of economic analysis.

Viability of the indicators

- A positive NPV means a BC ratio greater than one and a negative NPV means a BC ratio of less than one. Only those projects where the BC ratio is more than

one should be selected. The BC ratio facilitates simple ranking of alternative options in terms of their contribution to net benefits per unit of investment. The higher the BC ratio, the more viable is the project. In Bangladesh, BC ratio is the prescribed criterion by the government for selection of any projects.

- A project is economically viable if the IRR is greater than the interest rate; it is unviable if the IRR is less than the interest rate.

8.2.2 Risks and uncertainty

The evaluation of cost and benefit are the crucial part in calculating the BC ratio, EIRR or NPV. The advantage of economic analysis conducted through NPV, BC ratio or EIRR is that it is capable of incorporating risks and uncertainties of any planned projects. The uncertainties in connection with river bank erosion management projects are the morphology of the river, floods of different frequencies, probability of failure of bank erosion, real lifetime of a project, time actually taken for construction, future prices, occurrence of indirect and secondary consequences etc. Thus evaluation of benefit cannot be always made with certainty.

8.3 Fund Allocation of River Bank Erosion Management Project

Financing mainly depend on the political and economic structure of the country. In Bangladesh, different levels of Ministry share the responsibility of financing river bank erosion protection measures through Bangladesh Water Development Board (BWDB) as executing authority. BWDB has a mandate of executing bank protection work including its operation and maintenance.

8.3.1 Allocation of fund by the Government

Financing of a river bank erosion project raises several issues from an economic point of view. The costs of erosion management measures can be placed at different levels in society ranging from local community, local government, up to the national government, particularly in the outcome of severe bank erosion. The level of financing is determined through estimated cost based on technical and social viability. Generally, the structural options are capital demanding and the Government is taking the decision on their political will.

However, bank erosion management benefits consider as community benefits. It is not easy to determine the extent of benefit for any particular beneficiary to collect charges. This is the main reason why erosion management projects are usually financed by the Government. The private sector is usually disinterested in financing erosion management projects. As a result, long-term sustainability of the erosion management projects requires that a project should generate financial resources greater than or at least equal to the funds invested in the project.

The alternative options of non-structural measures such as preparedness, emergency response and recovery needs to be taken care of considering the risk-based approach to erosion management. These options for any bank erosion events have ample opportunities for financial contributions from individuals and communities. For example, the individual beneficiaries can contribute towards the maintenance of structural mitigation measures such as the patrol of revetments, spur, embankment which will reduce the burden of Government budget.

8.3.2 Fund recovery for bank erosion

The Government of Bangladesh is poorly prepared to assume the financial costs of bank erosion risk mitigation, response and rehabilitation. After serious bank erosion, Government often experience difficulties in allocating funds to assist the recovery process because of limitations on using taxes or diverting funds from other government or internationally financed projects. This is particularly true for severe bank erosion along the important bank where the damage is high relative to the country's gross domestic product (GDP). International lending organizations, such as the World Bank (WB), Asian Development bank (ADB) are sometimes asked by the Government to provide loans to aid the recovery process, after severe bank erosion. The Government of Bangladesh often experience difficulties in providing funds for bank erosion disaster response and rehabilitation, as well as mitigation of the losses. These difficulties can have long-term effects on the economies of Bangladesh and the welfare of the public.

8.4 Schematic Frame of Economic Management Aspects

Recurrent and extreme bank erosion creates serious risks to development and has negative impacts on lives, livelihoods and economic activity of the society. Integrated

bank erosion management plays an important role in protecting people and their socio-economic activities in floodplains from erosion. Economic analysis helps to select not only the optimum level of adjustment to erosion on the basis of risk-safety trade-off decisions but also can help arrive at an optimum combination of measures comprising both structural and non-structural. The functional relationship between outputs of this aspects and inputs of other aspects is shown **Figure 8.4**. This section provides a schematic frame (see **Figure 8.5**) for decision-making processes at various levels: action plan (planning), economic analysis, financial analysis, project design and implementation including monitoring and evaluation, by linking with other relevant aspects such as technological, social, risk and environmental aspects. In order to minimize subjectivity in decision-making, sensitive economic analysis plays a key role in trade-offs and conflict situations.

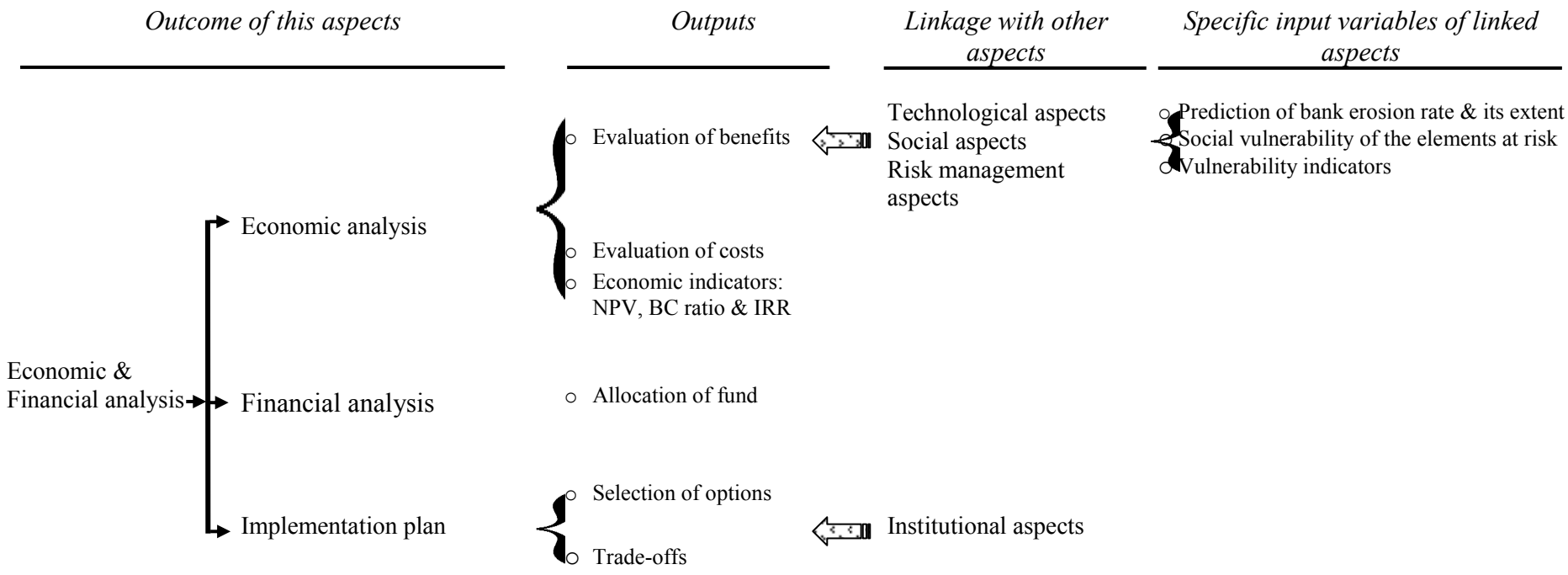
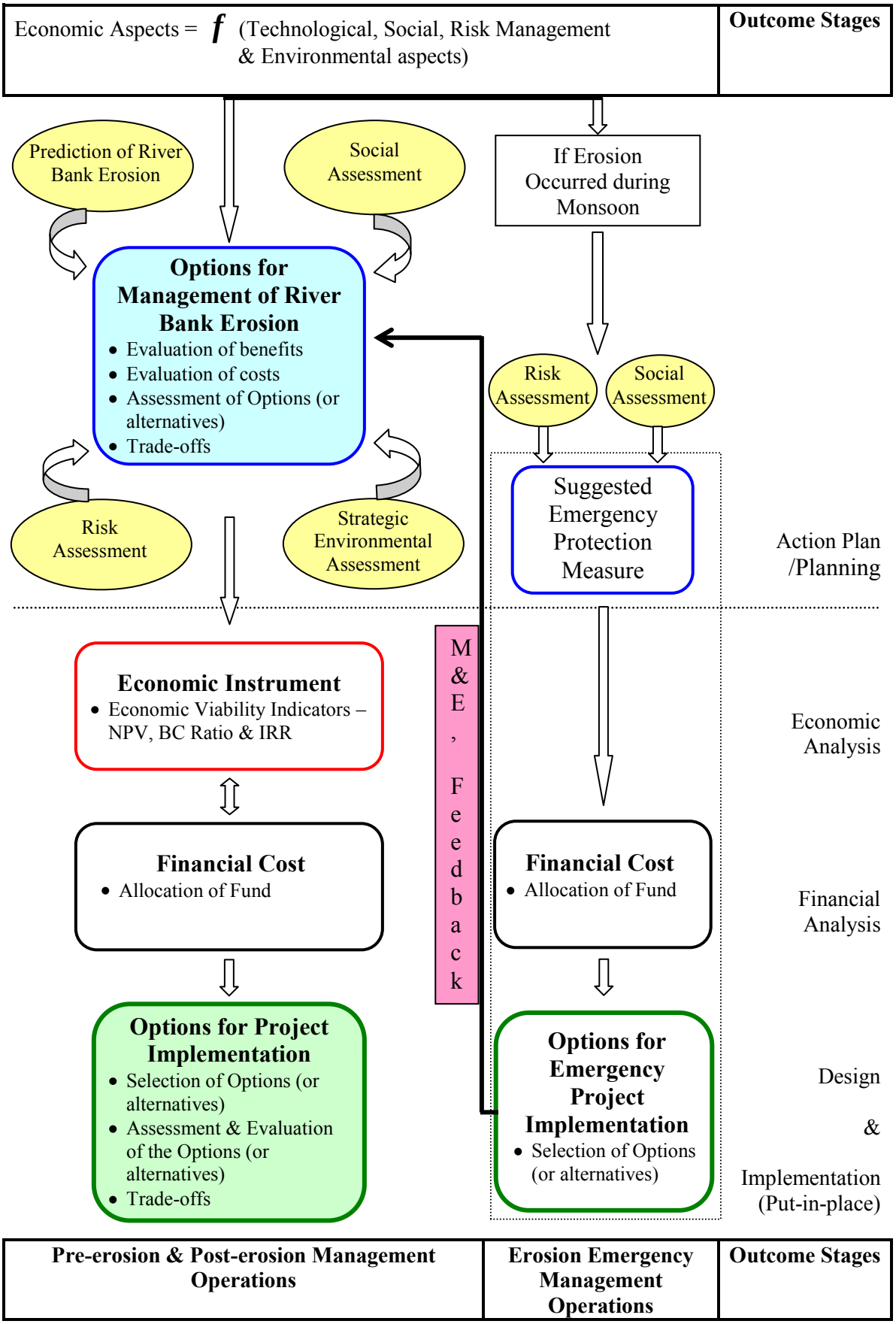


Figure 8.4: The functional relationship between input and output of independent and dependent variables

Figure 8.5: Schematic Frame of Economic Management Aspects



CHAPTER NINE

INSTITUTIONAL MANAGEMENT ASPECTS

Out of six aspects of IRBEM framework, this chapter describes the component of institutional management aspects. Stakeholder consultation reveals that the law related to IRBEM needs establishment of a framework that defines the rights, obligations of institutions and individuals at both the planning and operational phases of all stages of a river bank erosion management. Simultaneously, it also needs to provide an equitable framework for mitigation of river bank erosion ensuring security among different sectors of society. This framework may address appropriate mitigation measures through natural resource sharing, financial support and other techno-social measures. Additionally, an institutional framework needs to address the following specific issues:

- Proper management and collaboration among various organizations, institutions and stakeholders;
- ease of understanding and use of the fundamental data and information of bank erosion for planners and decision-makers;
- ensuring stakeholders participation at all stages of planning and operational phase;

9.1 River Bank Erosion Management Policy

The management policy of an institutional framework needs to be functioning according to the following three steps as an implementation process of bank erosion management:

(i) defines institutional set-up, roles and responsibilities,

(ii) determines and protects rights, powers, obligations of institutions and individual stakeholders and

(iii) determines mechanism for dispute management.

This research seeks to raise an awareness of policymakers/decision-makers regarding the need for an appropriate institutional framework for effective implementation of IRBEM.

River bank erosion management decisions must take into account considering their effect in terms of economic and environment on erosion risk alleviation following the context of IWRM. The decision making processes must take into account erosion risk because of their potential to affect the hydrological response of floodplains. In this regard, three aspects need to be addressed: (i) planning must be integrated with government's strategy; (ii) implementation process needs to be coherent and harmonized; (iii) stakeholder views and experiences must be communicated at all levels of planning.

In Bangladesh, the role of Ministry of Water Resources (MoWR) and Planning Commission is largely limited to the provision of administrative and financial support respectively. The line agency, Bangladesh Water Development Board (BWDB) is responsible for project formulation and its implementation by providing scientific and technical support taking on the principal duties of bank erosion protection.

Erosion hazard maps contain the basic information on its magnitude along the erosion vulnerable river banks and are the starting point of land use planning and regulation. Such maps should not only differentiate the extent and magnitude of erosion risks but also the sensitivity of such differentiation to various land uses. Based on the hydraulic characteristics of the concerned river, erosion hazard maps needs to be developed by the line agency (BWDB) indicating the probable bank erosion risk areas. The availability of erosion hazard maps to various stakeholders at local level should be ensured before implementing any mitigation plan. BWDB must take into account the factors that increase or affect the risks of bank erosion when making decisions regarding erosion mitigation measures, changes of land use and new structural interventions for erosion controls. The planning authorities must put in place the reliable erosion hazard maps to regulate development in areas of high risk. This obligation may be set out in legislation in binding policy documents such as NWPo of the government.

9.1.1 Participation of stakehoders

Stakeholder participation is an integral part of the IRBEM. The aim of IRBEM is to maximize the net benefits by minimizing the loss of land and property. Stakeholders referred to include property owners and the inhabitants of an erosion vulnerable area

and various interest groups. The sustainable bank erosion management refers the social, economic and environmental needs of the erosion vulnerable reach. These elements play a vital role in the planning and implementation processes of bank erosion management. The ultimate responsibility for the protection of private land/property, growth centers, towns etc. falls on Government though the affected people needs to take the responsibility by taking the precautionary measures to minimize the damage.

Useful stakeholder participation in pre-erosion management operations could be implemented through formal or informal way at different levels – local, regional and national. The participatory method for erosion management is essential by setting out the rights, obligations and powers of the public (individuals or particular groups) following formal approach with some legislation. In Bangladesh the poorer sectors of society, including elderly, women and children, are mainly sufferer in the bank erosion affected area. As such, participation of them is obligatory in building resilience of the communities. Field data experience from erosion-prone zones of Bangladesh indicates that the establishment of local erosion management association (LEMA) could be an effective platform for ensuring the participation of the affected people through institutional frame following the roles and responsibilities before, during and after bank erosion. A standard layout of a LEMA, which could be followed as a constitutive document, is illustrated in **Figure 9.1**. Experience also indicates that resilience-building measures at the community level are effective means of minimizing erosion losses. As a result, the role of public authority in raising awareness among erosion vulnerable communities is of great importance. In this connection, stakeholder analysis (SA) has been carried out to facilitate institutional and policy reform processes to incorporate the needs of those who have a stake or an interest (see **Figure 9.2**).

The identified local institutions for bank erosion/water management are BWDB, LGED, UNO and LGI/UP. The following information has been collected through key informant interviews (KII) to develop the institutional diagram (see **Figure 9.3**) in connection with LEMA. The institutional diagram in connection with LEMA functions has been developed by making relationship with other institutions.

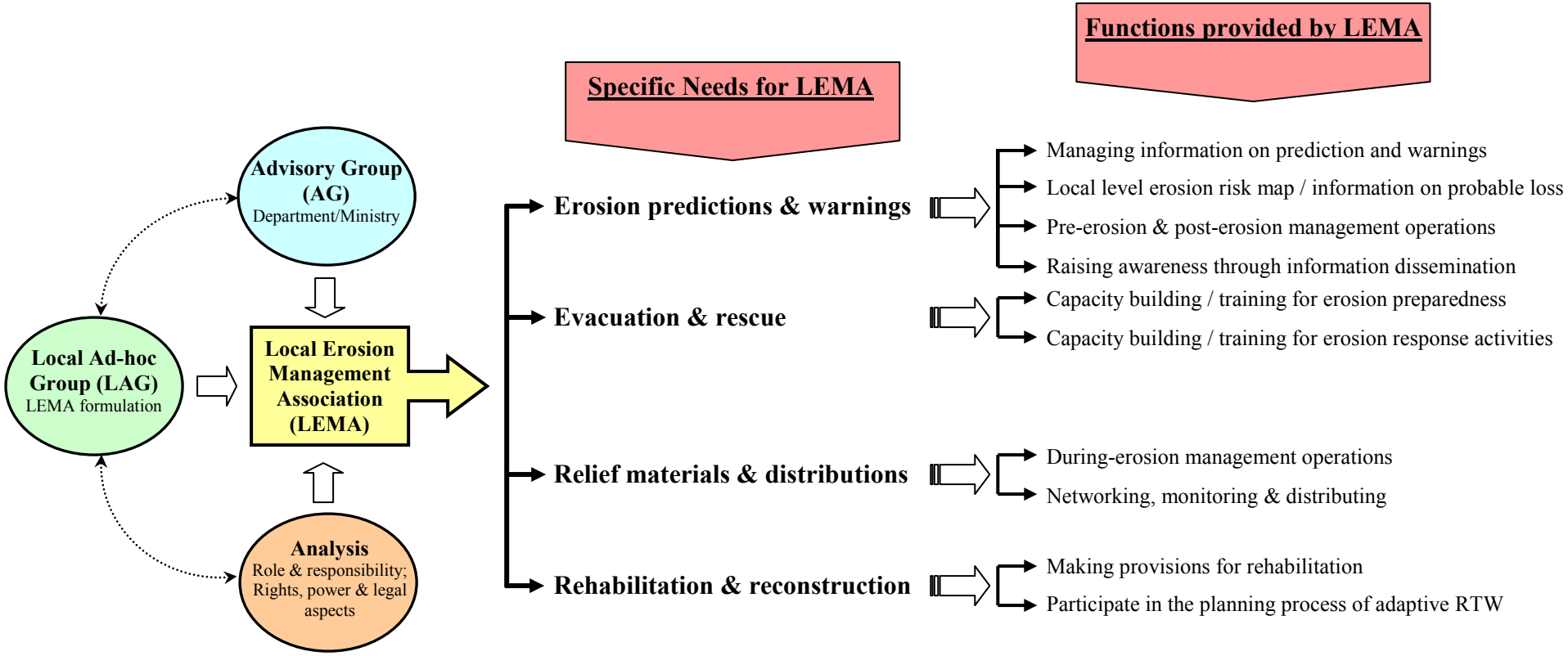


Figure 9.1: Set-up and functions of local erosion management association (LEMA)

Stakeholders		Actors	Degree of involvement	Reason for Chosen
Group	**Sub-group**			
Local Government Institution (LGI)	Union Parishad (UP)	User	Co-operating	Helping LEMA during emergency
	Upazila Nirbahi Officer (UNO)	Decision Maker	Co-thinking	Local level planning for emergency
MoWR	BWDB	Expert	Co-operating	Erosion management done by BWDB
		Decision Maker		
		Implementer		
Community	Agriculture (Ag)	User	Co-thinking	Affected by the erosion
	Farmer (Fa)			
	Fisherman (Fi)			
	Boatman (Bo)			
	Women (Wo)			
	Local People (LP)			

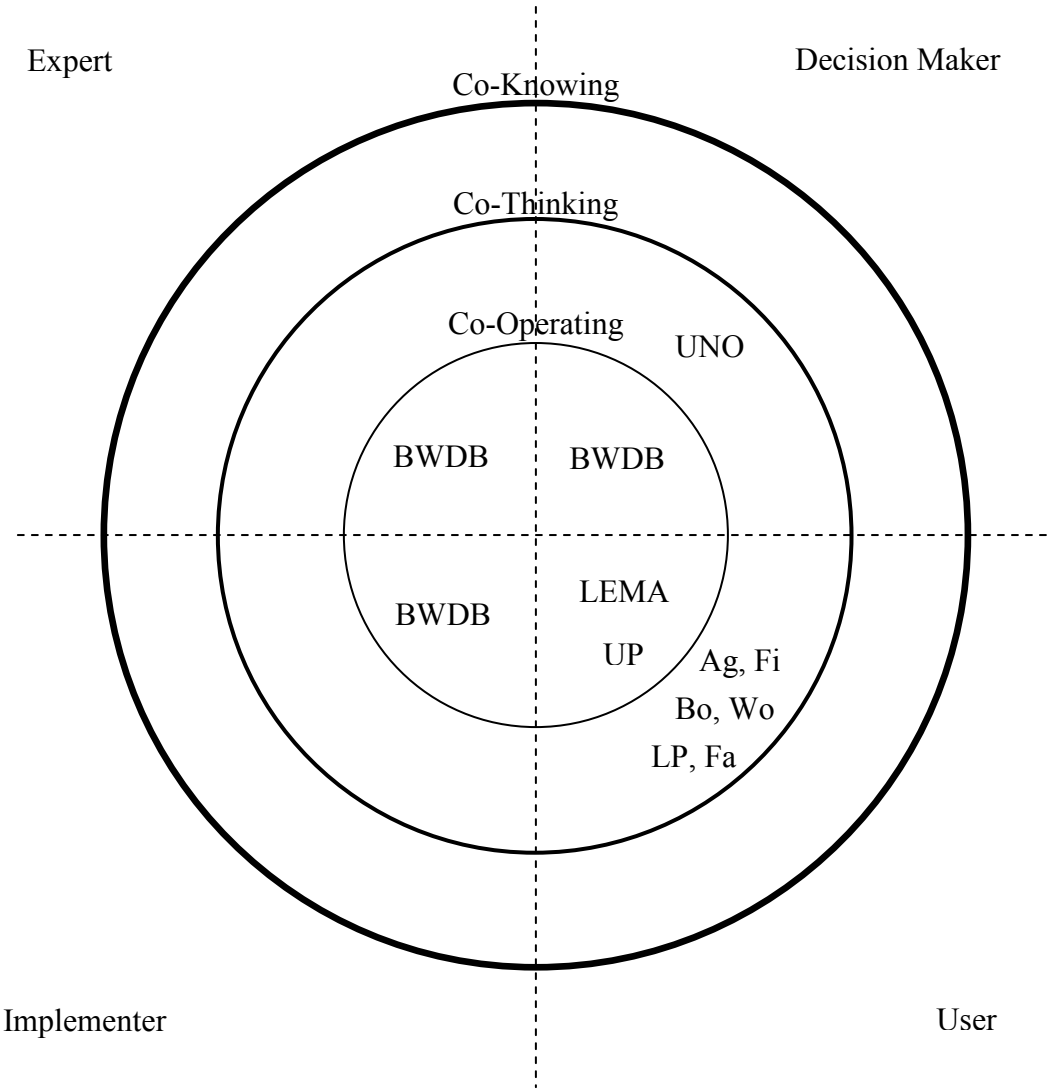


Figure 9.2: Local stakeholder diagram in connection with LEMA functions

Q1: What are the roles of erosion management?

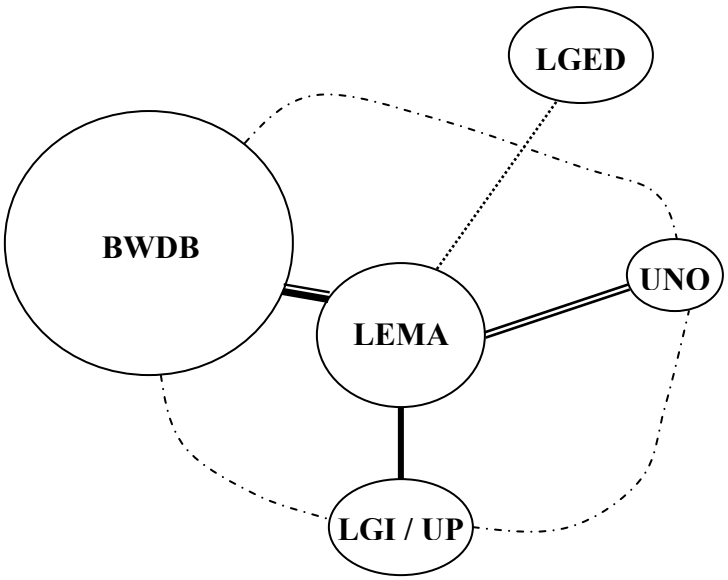
BWDB	LGED	UNO	LGI / UP
- BWDB has the mandate to protect the river bank from erosion; - BWDB is planning, designing & implementing bank protection work; - O&M of protection work done by BWDB.	- LGED dose not have any mandate for river bank protection work; - LGED only take care of protection work of road, bridge, culvert & small scale water resources project.	- only participate in the relief work during emergency;	- UP takes part in relief work & help in the emergency work; - UP resolution does not cover erosion protection work.

Q2: What would be the relationship of your institution with LEMA?

BWDB	LGED	UNO	LGI / UP
Co-operating	Co-knowing	Co-thinking	Co-operating

Q3: What are your suggestions regarding LEMA?

BWDB	LGED	UNO	LGI / UP
- idea is very good & BWDB always help LEMA	- LGED does not have any role for LEMA	- help LEMA during emergency	- LEMA will act properly if it is formed through UP resolution



Legend:

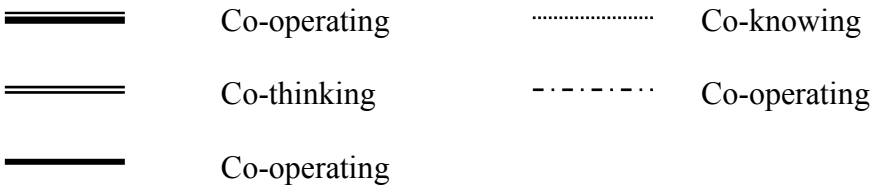


Figure 9.3: Institutional diagram in connection with LEMA functions

9.1.2 Protection of rights and powers of organization concerned

The responsibilities and duties of institutions and individual stakeholders should be set out and the details of the relevant functions must be well defined. IRBEM could be instructive to examine the nature of legal liabilities through right-based understanding in pre-erosion, during-erosion and post-erosion management operations. Rules and regulations will work as a legal right under a framework of the constitution of a country is shown in **Figure 9.4**. The rights of institutions and individual stakeholders must follow the rules and legislation for bank erosion management, ensure the agencies responsible for erosion protection, and ensure rights of compensation of the affected people. Moreover, continuous monitoring and evaluation must be ensured by the agencies responsible for erosion protection. An integrated right-based approach to erosion management indicates that there is a growing need to develop a group entity among the erosion affected people. This group entity can resolve the existing and potential conflicts in pre-erosion, during-erosion and post-erosion situations.

In addition, the agencies responsible for bank erosion management must have certain rights of access to the work for planning, designing and implementing to mitigate bank erosion. Since most of the eroded banks located on private property, it may not be possible for an agency to carry out its protection measures without the right access of monitoring and evaluation. In general, there is a corresponding right for the erosion affected land-owner for any damage due to construction of protective work. Considering these circumstances it is particularly important for the implementation authority while exercising their powers is open to both public scrutiny and challenges compiled with legal and administrative requirements. However, the local public authority such as LEMA may be responsible for disseminating erosion warnings at the probable bank erosion affected reach. The liability of the regional and national public authority for issuing such warnings needs to be based on scientific knowledge of the phenomenon causing floods and bank erosion in defining its limitations.

From an IRBEM standpoint, the rights and obligations regime may grow effectively on the ground for effective bank erosion management when invoked through right-based approaches.

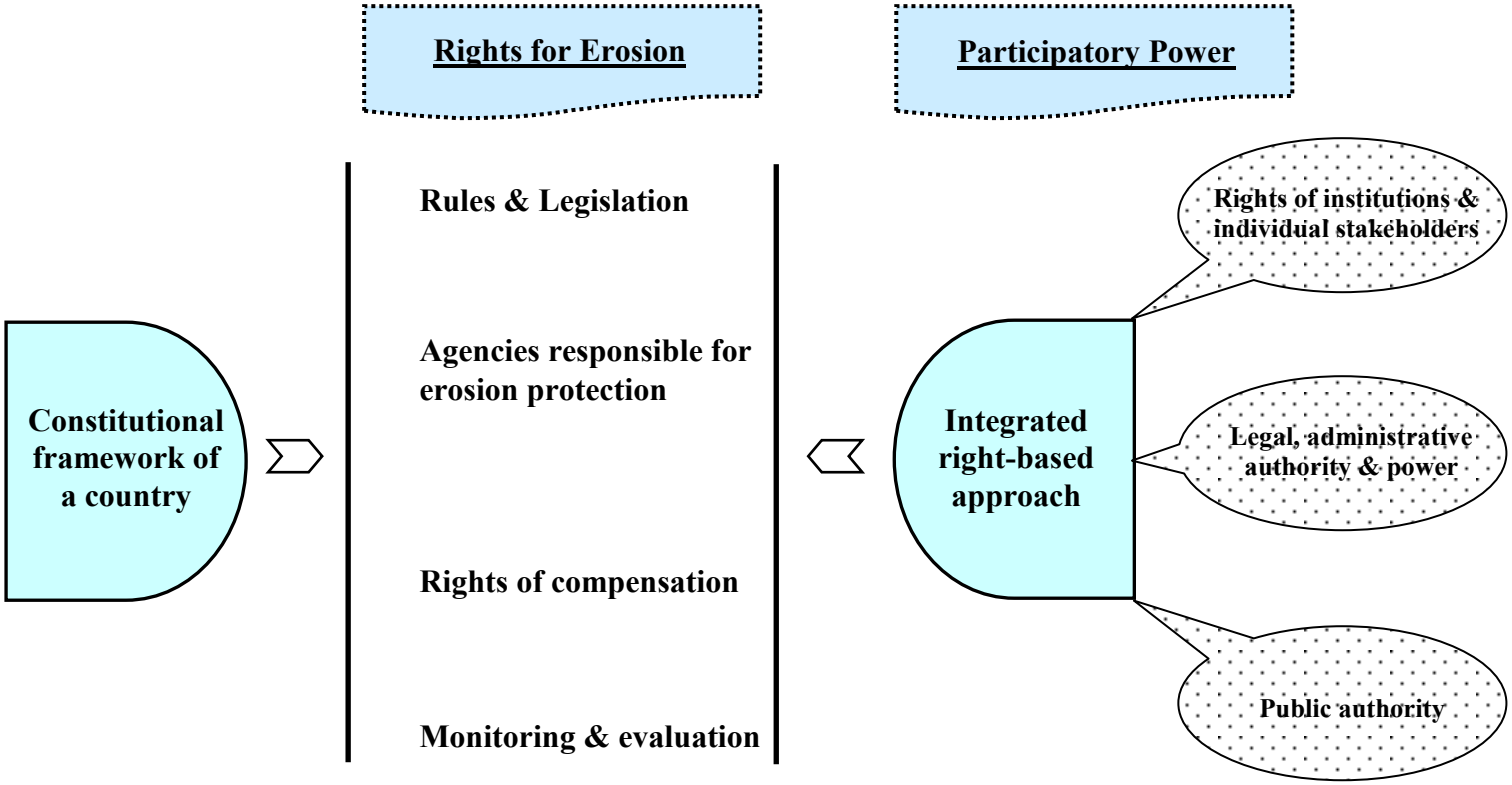


Figure 9.4: Rights and powers for erosion protection under a constitutional framework of a country

9.1.3 Institutional mechanisms for bank erosion management

Clearly the establishment of institutional mechanisms is imperative for Government in practicing IRBEM for effectively in managing bank erosion. The present institutional conditions in Bangladesh are not favourable for carrying out large-scale erosion management. The only institution which can take the lead in the development and implementation of a bank erosion mitigation measure is BWDB, but major institutional changes would be needed. At present, a project has been taken up while bank erosion occurs through planning, designing and implementation in a piecemeal way. There is no central planning and implementation procedures for maintaining the major and regional major rivers from bank erosion. From the perspective of the need for IRBEM at least following three important institutional changes have to be made.

- BWDB implements its present development work through seven zonal Chief Engineer, where centrally river bank erosion management is lacking. In this regard, it is advisable to establish a Directorate of River Bank Erosion Management headed by Additional Chief Engineer. The mandate of that Directorate would be to develop and implement the most appropriate bank erosion management / river training strategy for the entire (major and regional major) river systems of Bangladesh. Once the river systems have been trained operation and maintenance work would be done through this Directorate. For instance, this Directorate could be comparable to the Deltadienst established in the Netherlands to implement the original Deltaplan.
- Necessary funds should be available for a longer time than a few years. The mitigation of river bank erosion work takes many years and needs to continue over the required period. So, it is not acceptable stopping the work without achieving the targeted goal that will involve losing the investments (structural / non-structural measures) made earlier.
- Acquiring knowledge and experience is a very important issue. This can only be achieved when sufficient career opportunities are created for staff as specialists who choose to build their profession in the proposed Directorate.

However, if BWDB would be made responsible for developing and implementing such a challenging bank erosion management strategy, this will boost up the self-

esteem of the BWDB engineers. Moreover, it should become an honour to work on such a project for some decades.

9.1.4 Mechanisms for dispute management

It is an obligation for the Government to settle the dispute among the bank erosion affected people by peaceful means. Various dispute mechanism options are available in order to resolve the stakeholders' different opinions. Negotiation is the simplest and least expensive means of resolving a dispute between two parties. Third party intervention and conciliation are also available to regional authority as a means of resolving their disputes. Another mechanism is to submit the dispute to arbitration or judicial judgment. Out of these three dispute mechanisms, any one would be applicable for bank erosion management work (see **Figure 9.5)**. The field survey investigation illustrates that bank erosion management issues should not be considered in isolation, but should form part of a wider legal framework for the utilization and protection of river bank erosion.

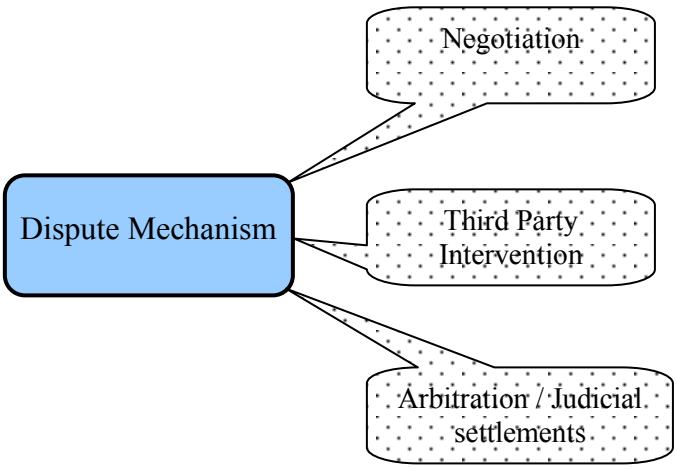


Figure 9.5: Dispute mechanisms for river bank erosion management

9.2 Analysis of Bank Erosion Management Policy

The preliminary steps for bank erosion management policy (see **Figure 9.6**) compelling with National Water Policy (NWPo) are:

Step1: situation analysis – it includes a brief outline of bank erosion issues as well as the overall legal and political environment in the context of country's development. This applies hydro-morphology of a situation and bank erosion risks in terms of social, environmental and economic condition.

Step-2: data analysis – the aim is to identify the relevant legal instruments and customize for bank erosion management. It needs to determine the issues related to bank erosion management and distribution of responsibilities between various administrative units. Bank erosion management programmes may also be governed by national documents such as policy documents (National Water Policy - NWPo), guidelines and best practice documents (National Water Management Plan – NWMP), which govern the way that decisions are taken, might not be legally binding, but may be relevant in the event of legal action. IRBEM essentially form part of overall IWRM, as such relevant national legal instruments are not only those directly dealing with bank erosion management, but a focus on land use, bank protection and conservation of eco-systems, human right to development and the participation of common stakeholders in decision-making.

Step3: gap analysis – it seeks to compare the provisions in the existing laws with the requirement of IRBEM and to identify gaps between what is required and what is available.

Step-4: Strength, weakness, opportunity and threat (SWOT) analysis – it seeks to identify opportunities and threats on the implementation process in order to guide a reform process.

If the gap analysis shows that there may be a need to reform the existing policy. In this regard, model legislation can be drafted in the context of local conditions. However, it is useful to examine the legislation at national level, successful and unsuccessful case studies, relevant guidelines or key principles. It is a satire that extreme bank erosion event represent the largest political will. The politician needs to maintain their political response by assuring the population for sustainable management. After severe bank erosion event, with mounting public pressure, it is appealing for political leaders to reassure the people by adopting a “bank erosion management” policy, suggesting that massive public investment into erosion defenses could solve the problem alone, without addressing whole array of erosion management options.

It is important to create a management system that is clear and unambiguous, flexible and at the same time robust for its effective implementation, compliance and enforcement. Practically, it is not possible to implement the reforms identified as required for various reasons. The government lacks the financial or institutional

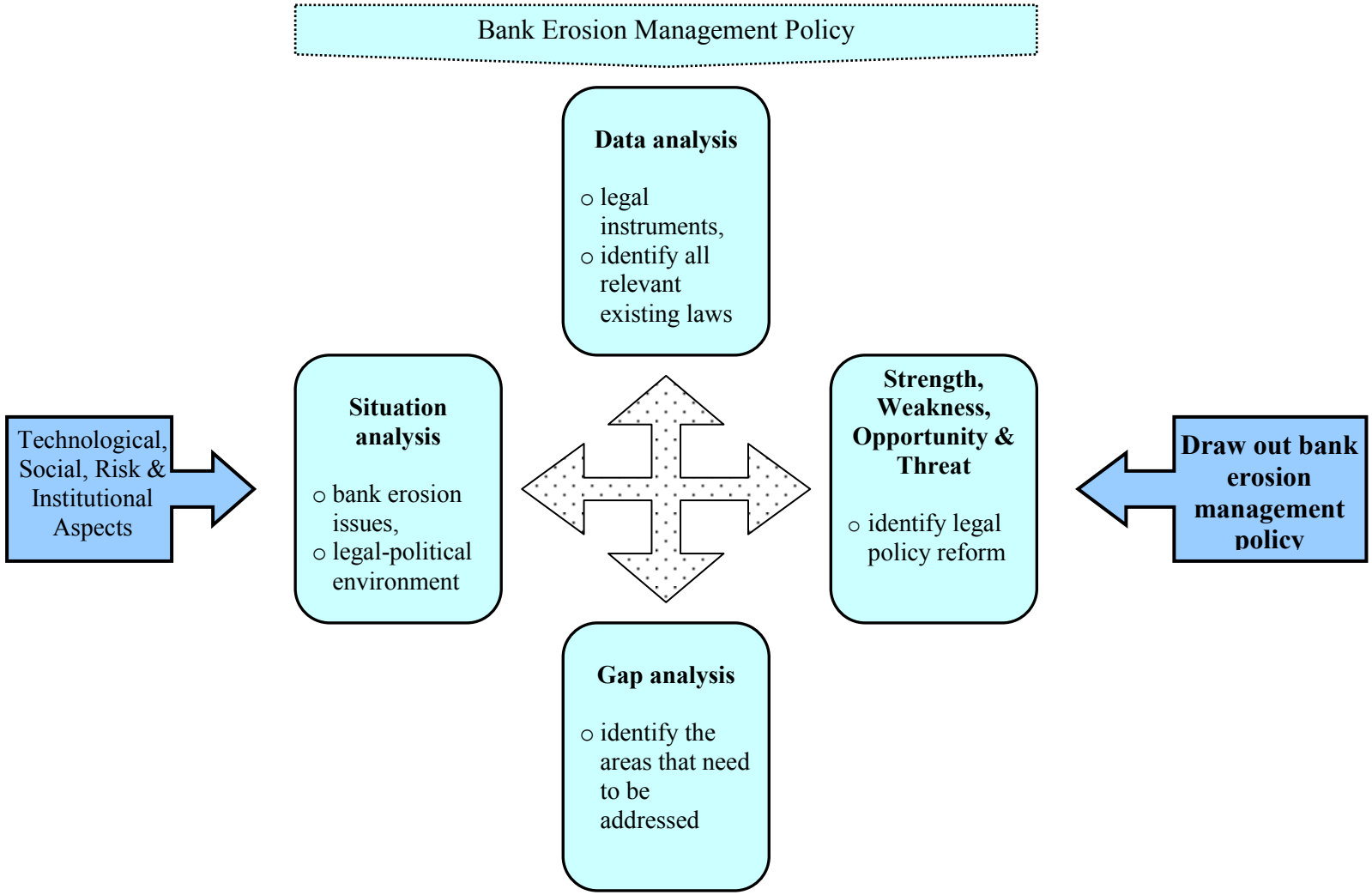


Figure 9.6: Methodological overview of the erosion management policy for IRBEM

capacity to design and implement the necessary reforms. A variety of legal issues, including liability for erosion damages, may need to address the reform process in the legislative framework. A successful institutional framework is one that is adaptive and responds to changing conditions by providing a clear sense of direction.

9.3 Schematic Frame of Institutional Management Aspects

IRBEM plays an important role in protecting people and their socio-economic activities in floodplains from bank erosion. A risk-safety trade-off decisions can be taken up through adaptive policy planning, defining law under an institutional framework. The functional relationship between outputs of this aspects and inputs of other aspects is shown **Figure 9.7**. This section provides a schematic framework (see **Figure 9.8**) for decision-making processes at various levels: policy planning, defining law and implementation including monitoring and evaluation, by linking with other relevant aspects such as social, risk and environmental aspects.

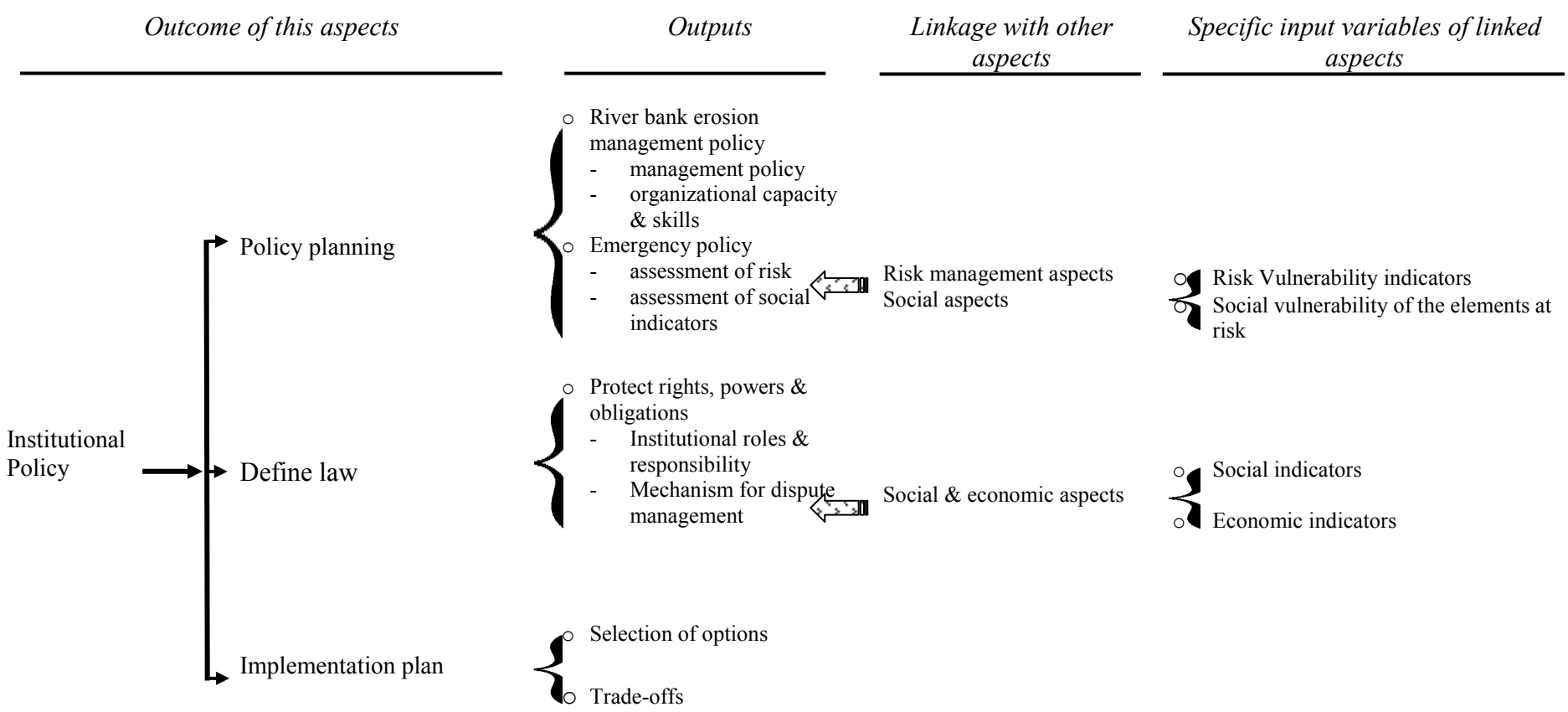
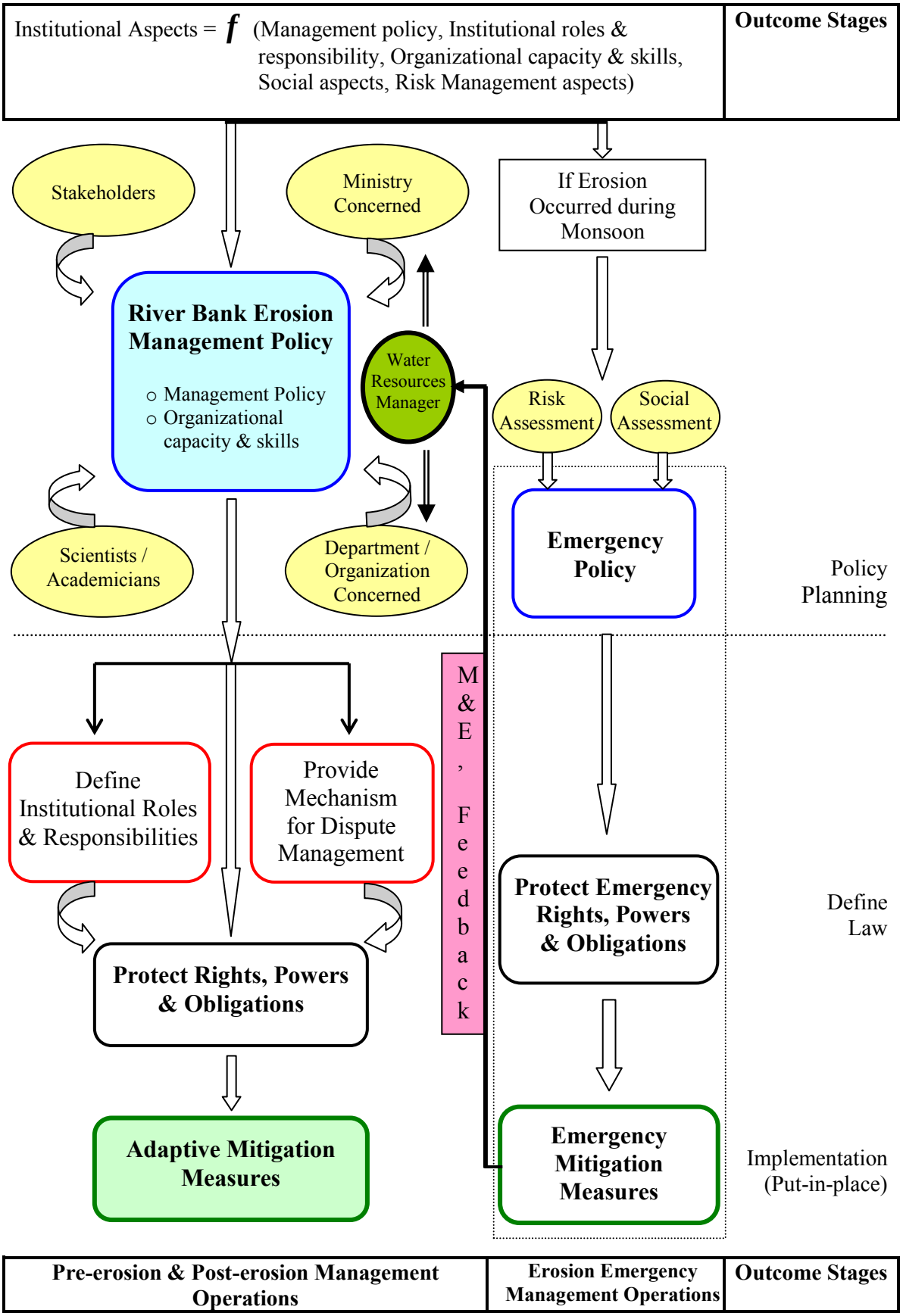


Figure 9.7: The functional relationship between input and output of independent and dependent variables

Figure 9.8: Schematic Frame of Institutional Management Aspects



APPENDIX - A

Erosion Victim Household Survey

1	Location:	Date:
2	Survey type:	Questionnaire Survey / Interview / FGD
3	Name of the respondents:	

Erosion related questionnaire

4	Occurrence of river bank erosion:	a. big flood b. medium flood c. average flood d. every year
5	When erosion occurs:	a. july-august b. september-october b. august-september d. july-september
6	At what time erosion occurs:	a. flooding time b. mid of flooding time c. ebbing time d. mid of ebbing time
7	Reason for river bank erosion:	a. not understand b. big flood c. extreme velocity d. extreme velocity & big flood
8	How can you understand about erosion:	a. not understand b. big flood c. extreme velocity d. extreme velocity & big flood
9	Yearly river bank erosion rate:	a. less than 10m/yr b. 11-20m/yr c. 21-30m/yr d. more than 30m/yr
10	Yearly extent of river bank erosion:	a. less than 15m along the bank b. 16-30 m along the bank c. 30-40 m along the bank d. more than 40m along the bank

Technological Management Aspects:

1 Identification of location of probable erosion prone bank:
a. identified
b. not-identified
c. not-possible

2 Prediction of river bank erosion rate:
a. predicted
b. not-predicted
c. not-possible

3 Prediction of extent of river bank erosion:
a. predicted
b. not-predicted
c. not-possible

4 Prediction of erosion severity:
a. predicted
b. not-predicted
c. not-possible

5 Predicted river bank erosion rate:
a. less than 5m/yr
b. 6-15m/yr
c. more than 15m/yr

6 Predicted extent of river bank erosion:
a. less than 10m along the bank
b. 11-20 m along the bank
c. more than 20m along the bank

7 Predicted area of erosion severity:
a. less than 50m2
b. 50 - 300m2
c. more than 300m2

Social Management Aspects:

1 Impact on income due to bank erosion:
a. low
b. medium
c. high

2 Impact on employment due to bank erosion:
a. low
b. medium
c. high

3 Impact on occupation due to bank erosion:

agriculture:
a. decrease
b. same
c. increase

labor:
a. decrease
b. same
c. increase

Service sector: a. decrease
b. same
c. increase

4 Impact on education due to bank erosion:

primary: a. decrease
b. same
c. increase

higher: a. decrease
b. same
c. increase

5 Impact on social dependency: a. low
b. medium
c. high

6 Impact on residential properties:

permanent homes: a. decrease
b. same
c. increase

mobile homes: a. decrease
b. same
c. increase

7 Impact on gender: a. low
b. medium
c. high

8 Impact on age: elderly: a. low
b. medium
c. high

children: a. low
b. medium
c. high

9 What are the negative/adverse impact on socio-economic activities:

a. loss of land, property & lives
b. loss of livelihoods
c. decreased purchasing & production power
d. psychological effects
e. hampering economic growth & development
f. political proposition

10 Social factors contributing vulnerability:

i. Poverty:	a. return from working land	decrease same increase
	b. food security	reducing same increasing
	c. earning potential	low medium high
ii. Livelihoods:		
	a. threaten the stability:	low medium high
	b. finding jobs to meet basic needs:	low medium high
	c. alternative options:	low medium high
iii. Cultural beliefs:		
	a. faith in social system	low medium high
	b. confidence in political decisions:	low medium high
	c. indigenous knowledge:	low medium high
iv. Human rights:		
	a. participation in mitigation plan	low medium high
	b. participation in response & recovery	low medium high
v. Gender inequalities:		
	a. child & aged suffer	low medium high

b. additional stress & fatigue: low
medium
high

c. women face privacy: low
medium
high

vi. Erosion victim groups:

a. safety of old people: low
medium
high

b. provision of special medical care: low
medium
high

c. awareness of erosion risks: low
medium
high

Risk Management Aspects

1 Eroded (to be eroded) land values:
a. low
b. medium
c. high

2 Infrastructures (buildings, roads, gc etc.) at risk:
a. low
b. medium
c. high

3 Strength & resilience of human beings:
a. low
b. medium
c. high

4 Sources of livelihoods (occupation):
a. low
b. medium
c. high

5 Peoples ability to protect environmental degradation:
a. low
b. medium
c. high

6 Initiative or leadership:
a. inadequate/lack
b. moderate
c. adequate

7 access to political power:
a. lack of /limited
b. moderate
c. unlimited

8	National & local institutional resources:	a. lack of/poorly b. good c. best
9	Participation in community development:	a. unequal b. equal c. jointly
10	educational background:	a. inadequate b. moderate c. adequate
11	social support network:	a. lack of/poorly b. good c. best
12	Access to national level:	a. limited b. moderate c. unlimited
13	Awareness of erosion mitigation measures:	a. low/lack b. medium c. high
14	Knowledge of development issues, rights & obligations:	a. low/lack of b. medium c. high
15	Dependency on external support:	a. low b. medium c. high
16	Exposure of human activities by means of:	
	i. non-structural measures:	
	a. erosion prediction:	undesirable justifiable desirable
	b. preparedness:	low medium high
	c. response:	low medium high
	d. recovery:	low medium high

ii. Demand of structural measures: low
medium
high

Environmental Management Aspects

A. Environmental issues related to study project location

		Impacts	IEE: potential effects/ impacts if unmitigated
1	Erosion of agricultural land & settlement:	insignificant (I) moderate (M) significant (S)	
2	Loss of crop land:	insignificant (I) moderate (M) significant (S)	
3	Loss of growth centers/towns land:	insignificant (I) moderate (M) significant (S)	
4	Sedimentation of river bed:	insignificant (I) moderate (M) significant (S)	
5	Resettlement of households:	insignificant (I) moderate (M) significant (S)	
6	Resettlement of growth centers:	insignificant (I) moderate (M) significant (S)	
7	Physical impacts on cultural heritage:	insignificant (I) moderate (M) significant (S)	
8	Construction of river bank protection work:	insignificant (I) moderate (M) significant (S)	

B. Environmental issues related project design

9	Bank scour at or near RBPW:	insignificant (I) moderate (M) significant (S)	

10	Risk of embankment breach:	insignificant (I) moderate (M) significant (S)
11	Risk RBPW failure:	insignificant (I) moderate (M) significant (S)
C.	Environmental issues during construction	
12	Safety of workers:	insignificant (I) moderate (M) significant (S)
13	Social issues:	insignificant (I) moderate (M) significant (S)
14	Resettlement of erosion households:	insignificant (I) moderate (M) significant (S)
15	Resettlement of growth centers:	insignificant (I) moderate (M) significant (S)
16	Pollution of water resources:	insignificant (I) moderate (M) significant (S)
D.	Environmental issues during operation	
17	Flow pattern of river during erosion:	insignificant (I) moderate (M) significant (S)
18	Impact on flora & fauna:	insignificant (I) moderate (M) significant (S)
19	Impact on gender issues:	insignificant (I) moderate (M) significant (S)
20	Preference about structural measures:	
	a. embankments	insignificant (I) moderate (M) significant (S)

b. revetments

insignificant (I)
moderate (M)
significant (S)

c. spur/groin

insignificant (I)
moderate (M)
significant (S)

21 Preference about non-structural measures:

a. erosion prediction & warning

insignificant (I)
moderate (M)
significant (S)

b. land use regulations

insignificant (I)
moderate (M)
significant (S)

c. emergency preparedness, response & recovery

insignificant (I)
moderate (M)
significant (S)

<u>Economic Management Aspects:</u>

Assessment of real erosion damage data

A. Previous year annual average erosion damage data:

1 Value of eroded land:

insignificant (I)
moderate (M)
significant (S)

2 Value of individual properties/assets:

a. domestic premises

insignificant (I)
moderate (M)
significant (S)

b. commercial premises

insignificant (I)
moderate (M)
significant (S)

c. retail & industrial premises

insignificant (I)
moderate (M)
significant (S)

3 Value of infrastructure damages
(building/school/college/mosque/road/electric poll etc.);

		insignificant (I) moderate (M) significant (S)
4	Value of agricultural damage:	insignificant (I) moderate (M) significant (S)
5	Value of drop out children's education:	insignificant (I) moderate (M) significant (S)
6	Value of income disruption:	insignificant (I) moderate (M) significant (S)
7	Resettlement value:	insignificant (I) moderate (M) significant (S)

B. **Predicted annual average erosion damage data**

8	Value of predicted eroded land:	insignificant (I) moderate (M) significant (S)
9	Value of individual properties/assets to be eroded:	
	a. domestic premises	insignificant (I) moderate (M) significant (S)
	b. commercial premises	insignificant (I) moderate (M) significant (S)
	c. retail & industrial premises	insignificant (I) moderate (M) significant (S)
10	Value of infrastructure damages (building/school/college/mosque/road/electric poll etc.);	insignificant (I) moderate (M) significant (S)
11	Value of agricultural damage:	insignificant (I) moderate (M) significant (S)

12	Value of drop out children's education:	insignificant (I) moderate (M) significant (S)
13	Value of income disruption:	insignificant (I) moderate (M) significant (S)
14	Resettlement value:	insignificant (I) moderate (M) significant (S)
15	Value of remaining property in erosion risk zone:	insignificant (I) moderate (M) significant (S)
16	Goodwill value for commercial entity:	insignificant (I) moderate (M) significant (S)

Institutional Management Aspects:

1 What are the specific issues that need to address in a legal framework?

a. coordination & cooperation between various institutions
b. availability & accessibility of the data & information
c. building enabling environment
d. others

2 What are the ethical & policy questions that need to be addressed before the law formulation?

a. how much river bank protection is prepared to pay for
b. will it protect property
c. responsibility of regional & national authority
d. others

3 What are the implementation processes of erosion management policy?

a. institutional set-up, roles & responsibility
b. rights & obligations of institutions
c. mechanism for dispute mechanism
d. others

4 What are the aspects needs to be addressed in the decision making process?

a. planning must be integrated with government's strategy
b. stakeholder views & experiences needs to be communicated at all levels of planning
c. others

5 What should be the monitoring processes for preparedness planning?

a. physical location of the erosion victim people
b. documentation & cost
c. time of consultation
d. awareness of stakeholders
e. others

6 What should be backed by laws to make decision in time regarding emergency response?

a. issue of erosion warning
b. legal means to enforce an evacuation sub-plan
c. security of assets left by the evacuees
d. media coverage of erosion forecasts and warnings
e. demarcating the erosion vulnerable area
f. others

7 How enabling stakeholders' participation can be ensured?

8 What are the specific needs for local erosion management approach?

a. erosion prediction & warnings
b. evacuation process
c. rehabilitation
d. others

9 What are the rights & powers for erosion protection under a constitutional framework?

a. rules
b. agencies responsible for protection
c. rights
d. monitoring & evaluation
e. others

10 What would be the institutional mechanisms for BWDB?

11 What are the components of dispute mechanism?

a. negotiation
b. third party intervention
c. others

12 What would be the basic components of Rapid Legal assessment Tools (RLAT) in erosion management?

a. contextual background
b. existing laws
c. existing laws with IRBEM requirements
d. opportunities, limitations & constraints
e. others

Data Analysis (example of scoring method)

1	Location:	ChanderChar			
2	Survey Type:	Interview (Questionnaire)			
3	No. of Respondent (s):	1	Total points:	1x3	3
			Total GPA:		10

Technological Aspects

		identified(3)	not-identified(2)	not-possible(1)	Total Score	Avg. Score
1	Identification of location of probable erosion prone bank:	3x1=3			3	10
		predicted(3)	not-predicted(2)	not-possible(1)	Total Score	Avg. Score
2	Prediction of river bank erosion rate:	3x1=3			3	10
		predicted(3)	not-predicted(2)	not-possible(1)	Total Score	Avg. Score
3	Predictioon of extent of river bank erosion:	3x1=3			3	10
		predicted(3)	not-predicted(2)	not-possible(1)	Total Score	Avg. Score
4	Prediction of erosion severity:	3x1=3			3	10
		< 5m/yr(1)	6-15m/yr(2)	> 15m/yr(3)	Total Score	Avg. Score
5	Predicted river bank erosion rate:	1x1=1			1	3.3
		< 10m along the bank(1)	11-20 m along the bank(2)	> 20m along the bank(3)	Total Score	Avg. Score
6	Predicted extent of river bank erosion:		2x1=2		2	6.7
		less than 50m2(1)	50 - 300m2(2)	more than 300m2(3)	Total Score	Avg. Score
7	Predicted area of erosion severity:		2x1=2		2	6.7
						5.6

Note:

Erosion zone may be classified on he basis of GPA = 10

Low erosion zone =	0 - 4
Medium erosion zone =	4 - 6
High erosion zone =	6 - 10

Conditions:

a. If erosion location is identified then prediction not-possible (rate, extent & severity)
>>> other aspects analysis does not recommend the type & extent of mitigation measures

b. If erosion location is identified then (rate, extent & severity) not-predicted
>>> other aspects analysis could be done supposing rate, extent & severity would be assessed later on

c. If erosion location is identified then (rate, extent & severity) predicted
>>> other aspect analysis could be done to recommend the type & extent of mitigation measures

According to the above classification & conditions, ChanderChar area is fallen under medium erosion zone where immediate erosion protection is recommended

APPENDIX-B

Summary Sheet

Application of IRBEM Framework

Location: ChanderChar **River:** Nabaganaga

a) Erosion Assessment	**medium to high**
i) Emergency erosion severity:	**medium to high**
Social Impact Indicators:	medium to high
Risk of Vulnerability Indicators:	low to medium
ii) Total erosion severity:	**low to medium**
Social Vulnerability of the Elements at Risk:	low to medium
Risk of Vulnerability Indicators:	low
Environmental degradation constituents:	low to medium
Physical damage:	medium to high
b) Risk Assessment	**medium to high**
i) Social Factors:	medium to high
Social Impact Indicators:	medium to high
Magnitude of Erosion Hazard:	low to medium
ii) Vulnerability Conditions:	low to medium
Social Vulnerability of the Elements at Risk:	low to medium
Risk of Vulnerability Indicators:	low

c) Type & Extent of Mitigation Measures

Non-structural>>>>	**erosion early warning & preparedness**
Structural>>>>	**revetment + non-structural**

i) Magnitude of Hazard:

Erosion Assessment:	medium to high
Risk Assessment:	medium to high

ii) Environmental Indicators:

Land Use Regulations:	low
Preparedness, Response & Recovery:	low to medium

iii) Economic Indicators:

Assessment of Damage:	medium to high
Assessment of Exposure Cost:	low to medium

d) Design

i) Hydrologic and Hydraulic Design Parameter

Water Level	observed/simulated
Discharge	observed/simulated
Velocity	observed/simulated

ii) Morphological Parameters

Plan-form Characteristics	observed/calculated
Shifting and Widening of the River	observed/calculated
Bend Characteristics and Cutoff	observed/calculated
Channel Cross-sections and Scour Depth	observed/simulated

iii) Economic Indicators

Assessment of Cost	estimated
Assessment of Benefit	estimated
IRR, B/C Ratio & NPV =	ok

e) Implementation

i) Timing

Design & Tendering Work	before November
Implementation of Work (structural)	December to April

ii) Monitoring & Evaluation

Check with Early Warning Prediction	during monsoon
Bathymetric Survey	during monsoon
Bankline Survey	during monsoon
Flow Tracking	during monsoon
Measurement of Flow Velocity	during monsoon

Detail Analysis Sheet

Application of IRBEM Framework

Location: ChanderChar

River: Nabaganga

a) Erosion Assessment

i) Emergency erosion severity: **medium to high**

Scaling factor: Low (<1), Low to Medium (1-2) & Medium to High (2-3)

Actual extent of bank erosion at ChanderChar

Social Impact Indicators: **medium to high**

Indicators	**Index**	**Category**
1. livelihoods	loss	high
2. purchasing capacity	decrease	medium
3. poverty	increase	high
4. women sufferings	sufferings	low
5. income	decrease	high
6. employment	loss	medium
7. homestead	damage	high
8. occupation	change/displacement	medium

Risk of Vulnerability Indicators: **low to medium**

Indicators	**Index**	**Category**
1. land values	decline	medium
2. infrastructure	damage	low
3. strength of human beings	resilience	low
4. sources of livelihoods	decrease	medium
5. environment	degradation	low
6. social support network	poor	high
7. erosion mitigation measure	awareness	low
8. external support	expectation	high
9. local power	access to	low

ii) Total erosion severity:

Scaling factor: Low (1), Medium (2) & High (3)

Actual & predicted extent of bank erosion at ChanderChar

Social Vulnerability of the Elements at Risk:		**low to medium**
Indicators	**Index**	**Category**
1. land	loss	low
2. property: homestead	loss	low
3. lives	loss/threatend	low
4. livelihoods	loss	high
5. purchasing capacity	decrease	medium
6. poverty	increase	high
7. gender	sufferings	low
8. income	decrease	high
9. employment	loss	medium
10. economic growth	decrease	medium
11. occupation	change/irregular	medium
12. social services	dependancy	low
13. social status	income loss	medium
14. temporary shelter	mobile homes	medium
Risk of Vulnerability Indicators:		**low**
1. land values	decline	low
2. infrastructure	damage	
3. strength of human beings	resilience	
4. sources of livelihoods	decrease	low
5. environment	degradation	low
6. social support network	poor	low
7. erosion mitigation measure	awareness	
8. external support	expectation	low
9. political power	access to	
Environmental degradation constituents:		**low to medium**
1. Agricultural development	decrease	low
2. Poverty & consumerism	increase	medium
3. Population growth	nutrients	medium
4. Urbanisation	decrease	
5. Industialization	decrease	
6. land use & settlement	mobility	medium

Physical damage:		**medium to high**
1. loss of land	110ha	high
2. loss of homestead	300 nos.	medium
3. loss of infrastructures	20 nos.	medium
4. loss of lives	6 persons	high
5. growth centre shifting	2 times	medium

b) Risk Assessment

Magnitude of Erosion Hazard:		**low to medium**
1. Actual extent of erosion	rate	medium
2. Predicted extent of erosion	rate	low

c) Type & Extent of Mitigation Measures

Land Use Regulations:		**low**
1. Regulating Bank Erosion	plan	
2. Regulating Infrasturture Development	plan	
3. Regulating Agricultural land	plan	low

Prepardness, Response & Recovery:		**low to medium**
1. Prepardness	plan	low
2. Response	plan	
3. Recovery	plan	low

Assessment of Exposure Cost:		**low to medium**
1. Prepardness	cost	low
2. Response	cost	low
3. Erosion early Warning	cost	medium
4. Resettlement	cost	medium
5. Structural	cost	high

Assessment of Benefits:

1. Past annual average damage data	Tk.	63445000
2. Predicted annual average damage data	Tk.	9980000
Total Benefits Costs:	Tk.	73425000

Assessment of costs:

1. Cost allocated to river bank protection	Tk.	55600000
2. Cost allocated to resettlement	Tk.	11600000
4. Cost allocated to agricultural development	Tk.	2800000
Project Cost:		70000000

Location: ChanderChar **River:** Nabaganga

Assessment of Benefits:

1. Past annual average damage data

Item	**Quantity**	**Unit**	**Rate (Tk.)**	**Amount (Tk.)**
Value of eroded land	35	ha	90000	3150000
Value of individual properties/assets				
- domestic premises	300	no.	20000	6000000
- commercial premises	50	no.	35000	1750000
- retail & industrial premises	30	no.	30000	900000
value of infrastructure damages				
- building	9	no.	150000	1350000
- school	3	no.	100000	300000
- college		no.		
- mosque	2	no.	60000	120000
- road	5	length, km	200000	1000000
- electric poll		no.		
Value of agricultural land	75	ha	65000	4875000
Value of income disruption		LS		5000000
Resettlement value	1300	person	30000	39000000
				63445000

2. Predicted annual average damage data

Item	Quantity	Unit	Rate (Tk.)	Amount (Tk.)
Value of eroded land	10	ha	90000	900000
Value of individual properties/assets				
- domestic premises	12	no.	20000	240000
- commercial premises	5	no.	35000	175000
- retail & industrial premises	9	no.	30000	270000
value of infrastructure damages				

- building	2	no.	150000	300000
- school		no.	100000	0
- college		no.		
- mosque		no.	60000	0
- road	3	length, km	200000	600000
- electric poll		no.		
Value of agricultural land	13	ha	65000	845000
Value of income disruption		LS		5000000
Resettlement value	55	person	30000	1650000
				9980000

Total benefits in monetary terms
= 73425000

Assessment of Costs:

		Quantity	Unit	Rate (Tk.)	Amount (Tk.)
Step1:	Justifiable expenditure for river bank protection	900	m	60000	54000000
	Justifiable expenditure for resettlement	200	person	50000	10000000
	Justifiable expenditure for agricultural dev.	20	ha	60000	1200000
					65200000
	Total cost of the project=				**70000000**
Step2:	SC1=				58800000
	SC2=				14800000
	SC3=				6000000
Step3:	RJE1=JE1-SC1				-4800000
	RJE2=JE2-SC2				-4800000
	RJE3=JE3-SC3				-4800000
Step4:	1:1:1				
Step5:	RJC=				-9600000
Step6:	RJC1=				-3200000
	RJC2=				-3200000
	RJC3=				-3200000
Step7:	**Cost (bank protection) =**				**55600000**
	Cost (resettlement) =				**11600000**
	Cost (agricultural) =				**2800000**
	Total Project Cost:				**70000000**

Standardization of Indicators

Respondents: Erosion affected people (individual/community)

Score: Best to worst

Social Impact Indicators:

Indicators	Labels/change	Score (best to worst)
1. Demographic features	No. of adult	1. >= 3 2. 2 3. 1
	No. of earners	1. >= 3 2. 2 3. 1
	Age group of hh head	1. < 50 yrs 2. 50 – 70 yrs 3. > 70 yrs
	Change/displacement occupation	1. low 2. moderate 3. high
2. Loss of livelihoods	Work availability	1. >= 5 days a week 2. 3 – 4 days a week 3. < 3 days a week
	Agricultural mobility	1. remained same 2. partially turned into other labour 3. totally turned into other labour
	Non-agricultural mobility	1. remained same 2. partially turned into other labour 3. totally turned into other labour
	Women income	1. remained same 2. partial loss 3. total loss
	Land loss	1. no loss 2. partial loss 3. total loss

	Homestead	1. no damage 2. partial damage 3. total damage
	Employment motivation	1. motivated 2. a few 3. none
3. Income and poverty	Purchasing capacity	1. remained same 2. partial loss 3. total loss
	Housing (resettlement)	1. own land elsewhere 2. road/embankment side 3. neighbor/relative place
	Shifting homestead (community)	1. many 2. a few 3 none
	Micro-credit support	1. adequate 2. inadequate 3. no support at all
	Income generation scheme	1. many 2. a few 3. none
4. Women sufferings	Sanitation facilities	1. adequate 2. inadequate 3. no sanitation facilities at all
	Drinking water supply	1. good 2. average 3. poor
	Taking foods	1. 3-times a day 2. 2-times a day 3. 1-time a day
	Age group of woman head	1. < 50 yrs 2. 50 – 70 yrs 3. > 70 yrs
	Women-headed household	1. low 2. moderate 3. high

Risk Vulnerability Indicators:

Indicators	Labels/change	Score (best to worst)
1. Population exposure	Individual	1. exposure none 2. exposure substantial 3. exposure all
	Collective	1. exposure none 2. exposure substantial 3. exposure all
2. Land values	value decline	1. very low 2. low 3. high
3. Infrastructures	Educational institutions affected (school/madrasha)	1. none 2. a few 3. all
	Hat/bazaars affected	1. none 2. a few 3. all
	Kacha road affected	1. < 3km 2. 3 – 5km 3. > 5km
	Pucca road affected	1. < 3km 2. 3 – 5km 3. > 5km
4. Resilience	Individual	1. high 2. moderate 3. low
	Collective	1. high 2. moderate 3. low
	Dependency on external support	1. low 2. moderate 3. high
5. Sources of livelihoods	Change of agriculture	1. low 2. moderate 3. high
	Change- small business / industry	1. low 2. moderate

		3. high
	Others	1. low 2. moderate 3. high
6. Environment	Structural interventions	1. adequate 2. a few 3. none
7. Social support network	Social bonding	1. high 2. moderate 3. none
	Conflicts affected / non-affected	1. none 2. moderate 3. high
8. Mitigation measures	Awareness	1. high 2. moderate 3. none
	Peoples indigenous knowledge	1. high 2. moderate 3. none
9. External support	Expectation – local	1. low 2. moderate 3. high
	Expectation – regional	1. low 2. moderate 3. high
	Expectation – national	1. low 2. moderate 3. high
10. Local power	Access to	1. high 2. low 3. none