Functioning Hydraulic and Morphological Sustainability of River Training Works in Bangladesh

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Abstract: River dynamics play the most vital role in the socio-economic of the country. These rivers are highly dynamic in nature which causes extensive riverbank erosion. Active river bank erosion and bed scouring, is apprehended to change the scenario, leading to loss of limited valuable land of Bangladesh. River training is being practiced in Bangladesh since 1960s but the process is very expensive especially in the Ganges and the Jamuna Rivers. Five types of river training works were selected at different reaches. Hydro-morphological characteristics of the major rivers are being evaluated not only in engineering concepts but also in socio-economic and environmental aspects. PRA (participatory rural appraisal) tools were applied to evaluate protection safety, hydraulic and hydrological connectivity, ecological and environmental characteristics, causes of failure and social acceptability. This comparative study is being carried out for closing the gap between the modern river training works and in country experience through adaptation of research findings with a view to effectively arresting river bank erosion. Sirajganj Hardpoint, Chandpur Town Protection work and Nakalia Revetment are found to be suitable and effective. A technically suitable structure may not have good social acceptance without IWRM (integrated water resource management).

Key words: Sustainability, river training works, river morphology, socio-economic, PRA tools, IWRM.

1. Introduction

Bangladesh is a floodplain country, where intensive river networks are the natural lively elements maintaining unique bio-diversity keeping about huge population with the most densely settlement on the earth. River dynamics play the most vital role in the socio-economic of the country. River erosion and accretion, periodical floods, natural adaptation of the society to the hydrological regime as well as its bio-resources from the time immemorial, shows high potential to survive and adapt with new-fangled situations shown in Fig. 1. The erosion and shifting of river courses, loss of land, especially along the Jamuna have long been recognized as a natural problem that affects a sizable population [1, 2] in

Bangladesh. The secondary current in a bend of a third order channel of braided river is similar to that of the single thread meandering channel [3]. The influence of secondary currents on flow and sediment dynamics causes meander shifting through river bank erosion and bar formation in typical meandering river [4]. The bank material characteristic along the Jamuna River is fine sand and almost uniform with respect to flow resistance (FAP1, 1993). The overall width of the river exhibits an increasing trend and there is tendency of shifting westwards, especially at the upstream part of the Jamuna river [5, 6]. To mitigate the above problem, historically BWDB (Bangladesh Water Development Board) is being implemented a number of river bank protection structures such as embankments, groins, revetments, spurs, hardpoint etc. [7]. Integrated river basin management is basic requirement of any project. River bank erosion and its protective measures are very important for sustainable

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Fig. 1 Location of the erosion prone areas of Bangladesh.

river management. Protective measures may vary as per river characteristics, social attitudes, knowledge and practices of executing agencies. The pattern and intensity of riverbank erosion largely depends on the hydro-morphological characteristics of the river. Bangladesh consist major part of the Bengal Delta. Except a few parts such as Barind Tracts, Madhupur Tracts, Lalmai Hills and Chittagong Hill Tracts, all plain land of the Bangladesh have been formed by the recent sediment, which is high erosion prone by its characteristic.

River training and erosion control is very expensive, especially in the Ganges and the Jamuna Rivers. River training is being practiced in these rivers from 1960s. For example, in order to confine the flow within a single deep channel for navigation or to control the bank erosion to protect city, homestead or valuable lands. Bandalling is practiced for navigation where as revetment works, Hardpoint, Groyne, spur, guide bank, closing of secondary channels are practiced for protection bank erosion. Most of the erosion protection works were either solid spurs or revetment works to protect important locations like Kamarjani,

Fulchari, Sariakandi, Kazipur and Sirajgonj in the Jamuna River. In case of the Ganges River, river training have been used in many places like: Panka Narayanpur, Godagari, Rajshahi, Sarda, Pakshey, Pabna, etc. along the left bank. After the devastating flood in 1988, RSP (river survey project) FAP21 and FAP22 [8] studied river bank erosion problems of the major rivers of Bangladesh. FAP21 selected the critical locations for river training along the right bank of the Jamuna River [9]. During 1996 to 1998 some special protection measures are taken (Sariakandi and Mathurapara hardpoint, Sirajgonj hardpoint and strengthening of Kalitola groyne) engaging foreign consultants and contractors with World Bank Loan. After wards in connection with Jamuna Bridge; Bhuapur Hardpoint and Jamuna Bridge guide banks are constructed by foreign consultants and contractors. These special river training works were very costly in comparison with the protection work done by BWDB [10, 11] itself. In spite of the Jamuna River bank protection works, BWDB has done huge erosion protection works throughout the country with revetment, solid or permeable spurs, porcupines along the Ganges, the Padma, the upper and lower Meghna, Teesta, Gumti, Kushiya, Surma, Mohanada, Atrai, Dharla, Dudkumar and many other rivers.

2. Methodology

2.1 Identification of Method and Selection of Reaches for Actual Field Investigations

Five types of river bank protection structures usually used were selected. They are shown in Table 1. During field investigations, the technical and social aspects will be taking into considerations of different geo-morphological setting of the country and river systems are shown in Fig. 2.

2.2 Preparation of Checklist

A checklist has prepared to carry out the technical and social investigations on selected river training and

bank protection works. It may be noted that any river training works should consider technical issues as well as social needs.

2.2.1 Carrying out Technical Investigations

Types of structures, cost, stability and its performance are mainly governed by the morphological characteristics of the concerned river such as planform, bed material size, scour depth, flow

velocities. Most of the structures, except the Chandpur bank protection work, are constructed in the recent past and they are not older than one and a half decades. Planform of the Jamuna is braided and the planform of the Pamda and some reaches of the Ganges vary between braided and meandering. A structure may experience the attack of different intensities of flow. Betil and Enyatpur structures

Table 1 Types of structures and their location studied.

Type of structures	Name of reaches for structures
1. Hard point	Sirajgonj (Jamuna River)
2. Revetment (1) with concrete block; (2) with Geo-bag	Chandpur (Padma River), Godagari (Ganges River), Titporal (Jamuna river) Pabna (Jamuna River)
3. Groyne	Kalitola (Jamuna River)
4. RCC Spur	Enayetpur and Betil (Jamuna River), Chapai Nawabganj (Ganges River)
5. Bandals	Upstream of the Jamuna Bridge (left bank)

Fig. 2 Location of the studies area.

were exposed to a smaller channel, while the Sirajganj structure exposed to the flow of a major channel in 2009. It may happen that a few structures never exposed to the attack of main flow of the river during its short life time. In such cases technical performance of such structures could only be evaluated through evaluating the performance of similar structures in the same fluvial environment but that should be exposed to the attack of the main flow for couple of years during its life. To estimate the number of years, a structure exposes to the main flow of the river, time series satellite images available in CEGIS archive were used. Average bankfull width of the channel adjacent to the structure was assessed from the images. Using this width and regime relations derived by FAP 24 for the Jamuna, Ganges and Padma Rivers bankfull discharges of those channels were estimated. Regime relations are:

$$W = 8.97 Q^{0.57} \quad \text{Jamuna River} \quad (1)$$

$$W = 9.97 Q^{0.55} \quad \text{Ganges River} \quad (2)$$

$$W = 4.76 Q^{0.62} \quad \text{Padma River} \quad (3)$$

where, W is bankfull width (m) and Q is bankfull discharge (m^3/s). The bankfull discharge as estimated by FAP 24 for the Jamuna, Ganges and Padma Rivers are 50,000, 45,000 and 80,000 m^3/s , respectively.

2.2.2 Carrying out Socio-economic Investigations

An important part of this project is to study social needs regarding river training works and bank protection. Social needs also play an important role in the process of river training works of particular area. Local knowledge collected from local people to minimize river erosion risks should be given due consideration and might be a good tool for understanding which kind of river training works should be selected at the erosion prone area. Thus RRA methodology would be applied and checklist would be used, where target would be focused on river erosion process and consequent social responses. In addition, KII (key informant interview) procedures would be followed for cross-checking and improvements of RRA information. Key informants

will be the local knowledgeable people like retired engineer, physician, contractor, teacher, union parishad chairman and members, etc..

2.2.3 Preparation of Matrix

A matrix is a combination of indicators, which will assist in extraction of field information, compilation and analysis of existing river bank protection and erosion control practices in Bangladesh clearly show their effectiveness in terms of social requirements, and mechanisms of failures and attributes of river bank protection structures. An integrated approach is considered for preparation of matrix and will be based on literature review, expertise evaluation, field investigations for accommodation of cost effectiveness, sustainability, local views, community response, etc. for carrying out comparisons and deriving final conclusions on suitability of those river works.

3. River Morphology

3.1 Discharges

Bangladesh is a lower riparian country of the three mighty rivers: the Ganges, the Brahmaputra (Jamuna) and the Meghna and total 320 number of rivers flow through the country. These river systems drain a huge catchment area of about 1.72 million km^2 . The combined average annual discharge of these rivers is about 345,000 m^3/s and the combined peak discharge in the order of 200,000 m^3/s [12]. The combined peak discharge becomes higher when flood occur in the Ganges and the Jamuna in the same time. Normally flood in the Jamuna comes earlier than the Ganges.

3.2 Bed Slopes

Bangladesh is situated on the water course with gentle slope from north to south. It is situated between the foot of the world's highest mountain Himalaya lies in the North and Bay of Bengal in the south. Water surface slopes of the major rivers are very flat, e.g., average slope of the Ganges is 5 cm/km to 6 cm/km,

for Jamuna 7 cm/km to 9 cm/km and lower Meghna it is 3.5 cm/km to 4 cm/km. Water surface slope of the Northern and Eastern rivers are steeper, like Teesta, Dharla, Dudkumar it is 30 cm/km to 90 cm/km.

3.3 Sediment Discharges

Rivers in Bangladesh carry huge sediment every year, which make rivers unstable. Table 2 shows estimated volume of sediment carried out by different researchers based on the measurement at different periods. It shows that the estimates of Coleman [13], BWDB [14] and CEGIS [9] for the Jamuna and Ganges Rivers are close to each other and nearly equals to one billion tons per year. Out of this amount one third of sediment consists of fine sand and rest of the sediment consists of silt and clay.

3.4 Planform

Planform of the large rivers of Bangladesh such as the Jamuna, Ganges, Padma and Lower Meghna Rivers varies from braided to meandering. For each river planform also varies spatially and temporarily. The Jamuna River is mainly a braided river having length-averaged braiding intensity varying from 2 to 3 [9]. On the other hand, the Ganges is mainly a meandering river with a number of chute channels in some large meandering bends. Planform of the Padma and Lower Meghna River vary from straight to meandering and braided over time. Braiding intensity of the Padam River varies from 1.3 to 2.2.

4. Structural Sustainability

4.1 Characteristics of the Structures

The hard point including 2.5 km revetment at Sirajgonj, revetment with concrete block at Titporal, revetment with geo-bag at Nakalia-Bera, revetment concrete block at Chandpur and RCC Spur at Panka-Narayanpur are the defensive structures and revetment with concrete block at Rajshahi, RCC Spur at Betil-Enayetpur and bandals are the offensive structures. The main purpose of these structures is to reduce the flow velocity and minimize the river bank erosion.

4.2 Failure Mechanism of the Structures

Revetment concrete block at Chandpur and RCC Spur at Betil-Enayetpur are failed due to local scouring and cause mass failure. It is due to generation of high discharge around the structures. Revetment with Geo-bag at Nakalia-Bera, Revetment concrete block at Rajshahi, RCC Spur at Panka-Narayanpur and Kalitola Groyne are also failed due to local scouring and floodplain erosion. But bandals (temporary structure) failed due to hitting by direct flow and floodplain erosion.

4.3 People Perceptions

River training is being practiced in Bangladesh since 1960s. Bandaling is practiced for navigation where as revetment works, hardpoint, groynes/spur,

Table 2 Total suspended sediment load in the Jamuna, Ganges and Padma rivers (Source, CEGIS, 2010).

Source	Jamuna		Ganges		Padma	
	Period of sediment record	Suspended sediment (million tons/yr)	Period of sediment record	Suspended sediment (million tons/yr)	Period of sediment record	Suspended sediment (million tons/yr)
Holeman (1968)	-	800	1874-1879	1,600	-	-
Coleman (1969)	1958-1962	610	1958-1962	480	-	-
BWDB (1972)	1966-1969	553	1966-1969	494	1966-1969	755
CEGIS (2010)*	1993-1996	402	1993-1996	632	1993-1996	948

*Analysis was based on the sediment gauging by FAP 24.

guide bank, closing of secondary channels are practiced for bank protection. Most of the river training works were either solid spurs or revetment to protect important locations like Kamarjani, Fulchari, Sariakandi, Kazipur and Sirajgonj in the Jamuna River. In case of the Ganges River, protection structures have been constructed in many places like Panka-Narayanpur, Godagari, Rajshahi, Sarda, Pakshey, Pabna, etc. along the left bank. Hard point is very massive structure. According to local stakeholders, there was no indication of safety and were unsatisfied when the structures had failed. Revetment with Geo-bag at Nakalia-Bera, Revetment concrete block at Chandpur and RCC Spur at Betil, Enayetpur local people are satisfied by its present efficiency. It also increases their level of safety. Local stakeholder also felt safe (upstream) and satisfied considering the present efficiency of the Kalitola Groyne and Bandals structures but it is not strong in nature. Revetment concrete block at Rajshahi and RCC Spur at Panka-Narayanpur, the people felt very poor level of safety because the structure does not work effectively.

4.4 Ecology of the Adjacent Structures

According to local stakeholder and fisherman of some specific reaches, fishes were available before construction of hard point including 2.5 km revetment. But decreased significantly, after construction of the structure at Sirajgonj, revetment with concrete block at Titporal, revetment concrete block at Rajshahi, Kalitola groyne and RCC Spur at Panka-Narayanpur. Fishes are also available with geo-bag at Nakalia, Bera and revetment concrete block at Chandpur before construction. But there were no significant changes after construction of the structures. Small species of various fish are available before and after construction RCC Spur at Betil-Enayetpur but total amount of fish production is reduced. With Bandal structures fishing are more difficult.

4.5 Economic Activities

There are direct and indirect advantages of river training works such as hard point. The primary advantage is the fact that local people will be employed. Therefore, hardpoint may be considered as management tool for increasing the public return. The protection structure of Titporal revetment did not create any income, but it prevents flood damage to crops, property and infrastructure over an area of 30,000 ha, inhabited by 4-5 million people. The protection structure of Spur at Chapai Nawabganj (Panka Narayanpur) creates employment opportunities in agricultural sector. Some char lands are formed along the bank of the protection structure. The protection structure of Chandpur town protection work creates employment opportunities in fisheries group. Due to low water and backward water flow simultaneously, different types of fish populations dwell there. At present, the mole head of the revetment is used as an aesthetic place. In the Kalitola Groyne adjacent char land area, community people are poorly benefited by the protection structure. As per opinion of the local people, the bandal structure can save their valuable and fertile agricultural land from erosion to some extent. As a result of deposition of silt, the local people get the opportunity to cultivate rice, wheat, sweet potato, oil seed and pulses in newly deposited land near bank. Cultivation of peanuts in newly deposited char lands is another good option.

5. Results and Discussions

The protection work arises a little hope for safety among the local community. The riverine people of Bangladesh always help each other to shift from the affected area during any disaster. Their social bondage is very high. So, community level response is very prompt during any erosion disaster. Now a day, settlement pattern of riverine people is changing (liner to scattered), it is difficult to continue such community response. The socio-economic development depends

Table 3 Understanding the attributes of river bank protection and erosion control practices (technical).

Type of structures	Techniques (flow management)	Construction materials	Manpower	Longevity	Real longevity	Maintenance cost (qualitative)	Protection safety
1. Hard point including 2.5 km revetment (Sirajgonj)	Energy dissipation Flow diversion (Aggressive mode)	Mainly CC blocks and geo aprons	0.5 lac man days (Sirajgonj, Sariakandi, Kalitola)	As per design 20 years	10 years	Medium	High
2. Revetment with concrete block (Titporal)	Scour protection Energy dissipation Flow modification	Mainly CC blocks and geo aprons	0.5 lac man days (Sirajgonj, Sariakandi, Kalitola)	As per design 20 years	2 years	High	Medium
3. Revetment with Geo-bag (Nakalia, Bera)	Scour protection Energy dissipation Flow modification	CC blocks and sand-filled geo textile bags	Not specified	As per design 20 years	Smoothly operated	low	High
4. Revetment concrete block (Rajshahi)	Reduce flow velocity and divert the flow to the main channel	Mainly CC blocks and geo aprons	Not specified	As per design 20 years	1 year	Medium	Medium
5. Revetment concrete block (Chandpur)	Reduce flow velocity and divert the flow to the main channel	Mainly CC blocks and geo aprons	Not specified	As per design 20 years	Phase I: 20 years; Phase II: 2 years	Medium	High
6. Groyne (kalitola)	Flow diversion (aggressive mode)	Mud filling and CC block	0.5 lac man days (Sirajgonj, Sariakandi, Kalitola)	As per design 20 years	10 years	Very high	High
7. RCC Spur (Betil, Enayetpur)	Flow diversion (aggressive mode)	RCC piling, mud filing and CC block	Not specified	As per design 20 years	6 years	Medium	Low
8. RCC Spur (Panka -Narayanpur)	Flow diversion (aggressive mode)	RCC piling, mud filing and CC block	Not specified	As per design 20 years	2 years	Medium	low
9. Bandals	Flow diversion (conservative mode)	Bamboo and bamboo mat	70 person/daily	1 year (experimental)	1 year	Not specified	Very low

Note: The cost of the hard point including 2.5 km revetment (Sirajgonj) may defer to the cost that found from literature review.

Table 4 Dynamics of river processes (natural).

Type of structures	River characteristics (hydraulic)		River connectivity with natural setting (floodplain, town, river networks, etc.)		Bio-habitat (ecological and environmental considerations)	
	Pre-intervention	Post-intervention	Pre-intervention	Post-intervention	Pre-intervention	Post-intervention
1. Hard point including 2.5 km revetment (Sirajgonj)	River flow directly hit and cause severe bank erosion near adjacent area, branch but active channel	- Flow hit at hard point and diverted - Erosion reduce	Jamuna River, Sirajgonj Town, Low land floodplain with small channel	Jamuna River, Sirajgonj Town, destruction of low land floodplain with small channel	Large amount of fishes found earlier in Jamuna River and adjacent floodplain area	Fish production decreased due to destruction of floodplain area
2. Revetment with concrete block (Titporal)	River flow directly hit and cause sever bank erosion near adjacent area, branch channel	- Flow divert - Erosion reduce	Bogra, Bangali River, Jamuna River, flood plain area	Prevent merger of Jamuna and Bangali River	Different species of fishes was naturally available	Fish availability have become lesser than earlier
3. Revetment with Geo-bag (Nakalia, Bera)	River flow directly hit and cause sever bank erosion near adjacent area, branch channel	- Flow divert - Erosion reduce	Bera-Pabna, Jamuna, flood plain area	Bera-Pabna, Jamuna, flood plain area is reduce	Different species of fishes was naturally available	Fish availability have become lesser than earlier
4. Revetment concrete block (Rajshahi)	River flow directly hit and cause sever bank erosion near adjacent area, main but inactive	- Flow divert - Erosion reduce	Godagari-rajshahi, Padma River, small channel	Godagari-rajshahi, Padma River, small channel are destroyed due to silt deposition	Different species of fishes was naturally available	Fish availability have become lesser than earlier
5. Revetment concrete block (Chandpur)	River flow directly hit and cause sever bank erosion near adjacent area, main and active channel	- Flow hit at hard point and diverted - Erosion reduce	Padma, Meghna, Chandpur Town, Dhakatia River	Padma, Meghna, Chandpur Town, Dhakatia River	Different species of fishes was naturally available	No change determined in the fish availability
6. Groyne (kalitola)	River flow directly hit and cause sever bank erosion near adjacent area, branch and active channel	- Reduced velocity of water - Erosion occurs at adjacent downstream	Bogra, Bangali River, Jamuna River	Prevent merger of Jamuna and Bangali River	Different species of fishes was naturally available	Fish availability have become lesser than earlier
7. RCC Spur (Betil, Enayetpur)	River flow directly hit the adjacent area and erosion occurred, branch and active channel	- Reduced velocity of water - Erosion observed in adjacent char land-New arable land rise	Jamuna River, Enayetpur, Betil	Jamuna River, Enayetpur, Betil	Different species of fishes was naturally available	Fish decrease, Small fishes found beside Spur
8. RCC Spur (Panka -Narayanpur)	River flow directly hit and cause sever bank erosion near adjacent area, main and inactive channel	- Reduced velocity of water - Erosion observed in adjacent main land and spur site	Padma River, Chapai-Nawabgonj Sadar, floodplain area	Padma River, Chapai-Nawabgonj Sadar	Different species of fishes was naturally available	Fish availability have become lesser than earlier
9. Bandals	Branch channel, erosion occurs and destroy productive agricultural land	- Reduced velocity of water - Flow diverted. - Channel formed in adjacent area	Jamuna River, Madumoti River at downstream	Jamuna River, Madumoti River at downstream	Different species of fishes was naturally available	No change determined in the fish availability

Table 5 Integrated matrix.

Type of structures	A. (technical stability)			B. (river stability)			C. (failure causes)	D. (social acceptability)		
	Erosion threat	Protection Safety	Local availability (skilled labor, cons. mat.)	Hydraulic and hydrological	Connectivity	Ecological and environmental		Risks	Livelihood	Poverty
1. Hard point including 2.5 km revetment (Sirajgonj)	Medium	High	Not available	- Flow hits at hard point and gets diverted - Erosion decreased	Jamuna River, Sirajgong Town, destruction of Low land floodplain with small channel	Different species of fishes lesser due to destruction of floodplain area	Local scouring, Mass failure	Medium	Increased in transport and business sector	Low
2. Revetment with concrete block (Titporal)	Medium	High	Not available	- Flow divert -Erosion decreased	Prevent merger of Jamuna and Bangali River	Fish availability have become lesser than earlier	Local scouring, mass failure	Medium	Increasing in business, agriculture sector	Low
3. Revetment with Geo-bag (Nakalia, Bera)	Low	High	Available	- Flow divert -Erosion decreased	Bera-Pabna, Jamuna. Flood plain area are reduce	Different species of fishes was naturally available	Floodplain erosion	Low	Increasing in business sector	Medium
4. Revetment concrete block (Rajshahi)	Medium	Medium	Partly available	- Flow divert -Erosion decreased	Godagari-rajshahi, Padma River, small channel are destroy due to deposition	Fish availability have become lesser than earlier	Floodplain erosion, Local scouring	Medium	Agriculture, service	Low
5. Revetment concrete block (Chandpur)	Low	High	Partly available	- Flow hit at hard point and diverted -Erosion decreased	Padma, Meghna, Chandpur Town, Dhakatia River	No change determined in the fish availability	Local scouring, Mass failure	Medium	Increasing in fisheries sector	Medium
6. Groyne (kalitola)	Medium	High	Not available	- Reduced velocity of water - Erosion occurs at adjacent downstream	Prevent merger of Jamuna and Bangali River	Fish availability have become lesser than earlier	Local scouring, mass failure, Withdraw of sand from sub-surface	Medium	Changed from agricultural to agricultural labor	Low
7. RCC Spur (Betil, Enayetpur)	High	High	Partly available	- Reduced velocity of water - Erosion observed in adjacent char land - New arable land accreted	Jamuna River, Enayetpur, Betil	Fish production decrease, small size of fishes is found beside Spur	Local scouring	Low	Handloom, business	Low
8. RCC Spur (Panka -Narayanpur)	High	Poor	Partly available	- Reduced velocity of water - Erosion observed in adjacent main land and spur site	Padma River, Chapai-Nawabgonj Sadar	Fish availability have become lesser than earlier	Local scouring, Floodplain erosion	Low	Changed from agricultural to agricultural labor	Medium
9. Bandals	High	low	available	- Reduced velocity of water -Flow diverted - Channel formed in adjacent area	Jamuna River, Madumoti River at downstream	No change determined in the fish availability	Flow hit directly, Floodplain erosion	Medium	Opportunities create on agricultural sector	Medium

upon the stability of the bank protection works, which again depends upon the faith of the local people on structure. The local people are capable to play a vital role in the management of any emerging disaster. So, the community involvement is necessary for the management of such activities like construction of any river training works. It is noted that before taking any bank protection project, the societal needs and demands should be taken into consideration. It could be more fruitful and sustain as a whole for the societal wellbeing of the locality. The riverine people also suggested that the suitable time for construction of any river training works is in dry season. Implementation cost gets minimized due to cheap labor cost, because in dry season riverine people may get less work opportunity. A technically suitable structure may not have good social acceptance, which makes the evaluation considering all aspects very difficult. Therefore, a detailed study could give a better answer. In this study, all these issues (technical evaluation and ecological functioning) measures qualitative during focus group discussion, which need to be evaluated quantitatively, are not being explored in detail. Technical and natural analysis for preparation of integrated matrix is shown in Tables 3-5.

6. Conclusions

River plays the vital role in socio-economic of the country. River bank and bed scour associated with channel confluences and bends. Bank materials of the major rivers are mainly consisted of non-cohesive sediment such as sand, silt and a small amount of clay, which is highly susceptible to erosion. For the prevailing hydro-morphological characteristics of the major rivers performances of the structures are evaluated considering different aspects, such as stability, cost, safety and eco-friendly. From technical point of view, stability of the structure in the hydro-morphological condition of the river comes first. In this regard, hard point at Sirajganj, protection work at Chandpur and revetment work at Nakalia are found to be suitable. But the cost of hard point at Sirajganj

is very high where that of revetment at Nakalia is relatively cheaper. There are other low cost structures such as spurs at Betil-Enayetpur and Bandals. But these structures highly fragile to the normal strength of the flow of the braided channel. This structure could be put provisionally on very small braided channels to protect the less intensive erosion along those channels. A technically suitable structure may not have good social acceptance, which makes the evaluation considering all aspects is very difficult. Socio-economic and environmental consideration, river behavior and morphological features need to be clarified along the river systems. Land and water management should not be a stand-alone policy but rather an integrated way.

Acknowledgments

The authors express their gratitude to Mohammad Arifur Rahman, Mahmud Hasan Tuhin, Dr. Sujit Kumar Bala, CEGIS (Center for Environmental and Geographic Information Services) and IWM (Institute of Water Modeling) to provide their technical and financial support for this study.

References

- [1] K.M. Elahi, Riverbank Erosion, Flood Hazard and Population Displacement in Bangladesh: An Overview, Riverbank Erosion Impact Study, Jahangirnagar University, USA, 1991, pp. 95-110.
- [2] A.H. Chowdhury, M. Kabir, Socioeconomic and Demographic Characteristics of Displaces in Bhola and Kazipur: A Comparative Study, Riverbank Erosion Impact Study, Jahangirnagar University, 1991, pp. 111-122.
- [3] M.N. Uddin, M.D.M. Rahman, Flow and erosion processes at bends and around river training works in a sand bed braided river, Ph.D. Thesis, Bangladesh University of Engineering and Technology, 2010.
- [4] T. Nakagawa, J.C. Scott, Stream meanders on a smooth hydrophobic surface, *Journal of Fluid Mechanics* 149 (1984) 89-99.
- [5] FAP 1 (Flood Action Plan), in: Proceedings of the Third Conference, Water Development and Flood Control/Flood Plan Coordination Organization (FPCO), Ministry of Irrigation, Dhaka, Bangladesh, May 17-20, 1993.
- [6] FAP 24, Morphological Characteristics, River Survey

- Project, Annex 5, BWDB (Bangladesh Water Development Board), 1996.
- [7] Guidelines for Riverbank Protection, Jamuna-Meghna River Mitigation Project (JMREMP), BUET (Bangladesh University of Engineering and Technology), Bangladesh, 2008.
- [8] Bank Protection and River Training, Consulting Consortium, AFPM (advanced fluid physics module) pilot project, FAP 21/22, 1993.
- [9] CEGIS Prediction of River Bank Erosion along the Jamuna, the Ganges and the Padma Rivers in 2010, Jamuna-Meghna River Erosion Mitigation Project, Bangladesh Water Development Board, Dhaka, 2010.
- [10] Guideline to Planning and Design of River Training and Bank Protection Works, Bangladesh Water Development Board, Dhaka, Bangladesh, 1993.
- [11] Guidelines and Design Manual for Standardized Bank Protection Structures, Jamuna Test Works Consultants, Joint Venture, 2001.
- [12] C.E. Haque, Hazards in a Fickle Environment: Bangladesh, Kluwer Academic Publishers, The Netherlands, 1997.
- [13] J.M. Coleman, Brahmaputra River: Channel processes and sedimentation, *Sedimentary Geology* 3 (1969) 129-239.
- [14] Guidelines for River Bank Protection, Bangladesh Water Development Board and BUET, Dhaka, Bangladesh, 2008.