

Original Research Article

Usefulness of River Training Structures and Present Status in Patuakhali District Bangladesh

Running Title: Usefulness of River Training Structures and Present Status in Patuakhali District Bangladesh

ABSTRACT

Aims: The focus of this study was to know usefulness of river training structures to controlled hydro-morphological characteristics, socio-economic benefits of inhabitants and current situation of these structures in Patuakhali District.

Study design: Evaluations were measured on hydro-morphological features of rivers, protection safety based on performance of structures, environmental and social benefits by spot visit, face to face interview and focus group discussion methods.

Place and Duration of Study: Ten different river side location of Patuakhali District during July-Sep in 2015.

Methodology: Prepared worksheet to carry out the questioner and established 5 (five) groups (8 persons/group) in each location for evaluation on the basis of some key point issue by assigning score 1-6.

Results: Three categories of river training structure were found at 10 (ten) different location of the study area. Revetment with cement concrete (CC) block including 1.75 km bank protection measure from erosion due to high velocity tidal current at Lebukhali point (0.715km), Patuakhali town protection point 2 (0.62 km) and Khepupara Bandar & town protection (0.42 km). Among them Lebukhali point was found more offensive comparing with others points. The level of risk of all structures was averages under low to medium except Lebukhali point. The training structures were found moderately stable due to maintenance and effectively acting as qualitative benefits for inhabitants in socio-economic aspect.

Conclusion: Embankment construction materials are consists of sticky clay with a small amount of

silt and sand, which were found to be usefulness and sustainable for long time with proper maintenance.

Keywords: Usefulness, river training structure, present status, qualitative benefit.

1. INTRODUCTION

Bangladesh is predominantly a low-lying riverine country situated in the South Asian Sub-continent. There are almost 700 rivers including convergence of the Ganges (Padma), Brahmaputra (Jamuna), and Meghna and their tributaries were run through the country creating channel total length of about 24,140 km [1]. The physical characteristics, geographical position, climatic condition and auto-cyclic fluvial courses have produced numbers of big Multi-channel River following through the country with separate channel width of up to 5 km in which scour generated around 50 m depth [3]. The channel width becoming large and depth is reducing over the year due to unfavorable geographical location and the river flow control by the countries upstream reaches, that's leading to unexpected erosion-deposition processes along the river. As a result bank erosion and channel shifting of alluvial rivers are under serious problem to the social, economic and environmental aspect of the country [30]. The alluvial floodplain rivers are always flowing on common geomorphological process which causes of bank erosion. This is corresponds to river bank adjustment, bank trampling, navigations, variation of channel bed elevation and topography in reaction of modified the flow situation or river bank resistance, exceptional flooding and rising intensity of tidal waves [6, 14, 16, 17]. Thus, it's needed to carry out continuous observation and important to pay attention on geomorphological processes and management situation of the river timely. For example typical situations of lower part of Brahmaputra river bank protection system as well as its hydraulic and morphological consequences were measured by Zhang et al. [30].

These rivers are always self-regulatory in the way that, they modify their physical appearance or flow pattern in response to any variation of the environment. This environmental deviations may occur either naturally by climatic difference, heavy rain, breaking dam or levee or changes in vegetative cover, land slide etc. or maybe the results of human activities such as river training, channel narrowing, sand and gravel mining, channelization and bridge and highway construction. All these changes destroyed the ordinary quasi-equilibrium of river flow and in the process of restoring the steadiness of flow, which need to adjust to new situation by changing its slope, width, roughness etc.

40 In present constraints, any or combination of these features may adjust as the river seeks to maintain
41 the balance between its ability to transport and sediment load provided. Therefore, river channel
42 stability is a significant issue to understand overall river steadiness and recognition of present status
43 in many ways, such as: study of bank erosion, lateral instability hazards, construction of structures
44 along or nearby the river passageway, start on where to restore the river, exploit natural resources
45 and develop safe settlement zones [26].

46 The protecting measures of river bank erosion are very important for sustainable river management. It
47 depends and varies on river morphology, geographical location, social attitudes, knowledge and
48 practices of executing agencies. The amount of bank erosion mostly depends on the hydro-
49 morphological features and circumstances of the river. A major part of the Bengal Delta including all
50 plane land of Bangladesh have been formed from recent sedimentation, which is highly erosion prone
51 by its characteristic except Barind Tracts, Madhupur, Lalmai and Chittagong Hill Tracts [21]. In coastal
52 districts, most of the rivers were tidal and navigable throughout the year. Sometimes tidal surge were
53 hugely bump into the locality due to low pressure climatic condition. Dronkers [7] stated the
54 phenomenon of tides, those are created by the attraction of sun and moon with sea water which
55 visible that regular raise and fall of water within a range of several feet. The high water period
56 generally occurs twice a day and interval time between one and next averaging twelve hours. Here
57 rivers were trained to maintain the morphological equilibrium for social protection, environmental and
58 economic aspects, where buildup numbers of Polder. Though the purposes of this river training
59 structure are noble and credible, but implementation of such training activities without in-depth studies
60 and due to lack of careful consideration of the ecological balance of water and sediment would not
61 only aggravate the remaining problems also lead to various unexpected consequences and
62 irreversible damage [12]. In Bangladesh river training were practiced from 1960s by Bangladesh
63 Water Development Board (BWDB) [2]. During the later period of 1950s and from mid 1960s river
64 training works started from the west bank of the Jamuna river and extending for some 220 km [30],
65 but development of this training structure was very expensive especially in the coastal reason of
66 Bangladesh,. There are varieties of river training structures such as embankments or dikes, spur
67 dikes, groynes, revetments, guide bunds, marginal bunds etc. used to maintain a suitable channel for
68 the purpose of river bank protection, enhance the channel navigation and sustain the ecosystem of
69 the environment. Most of them like spur dike, groyne, revetment, and embankment are used for river

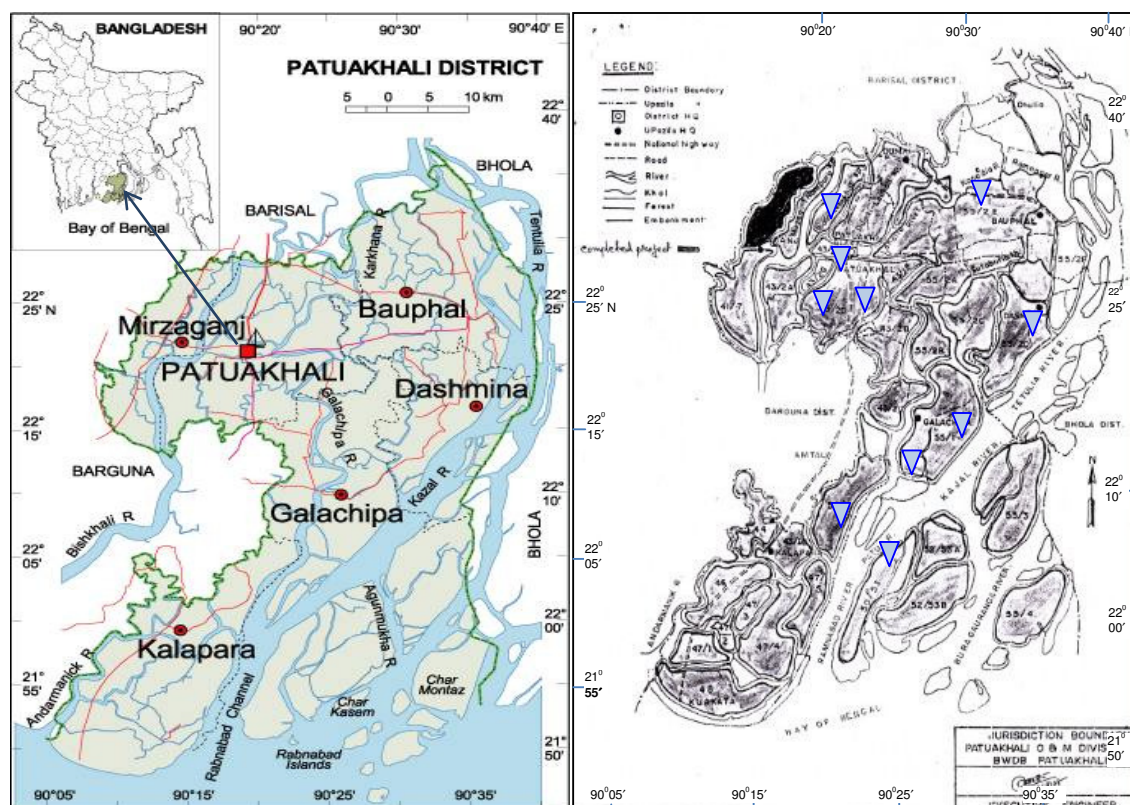
bank protection in Bangladesh. Since 1960's, a number of earthen embankments were constructed along the major rivers side of the country for the protection of rural community, fisheries, livestock's, agricultural lands from tidal flood. In the past several decades, frequent flood and continuous erosion have consumed large areas of floodplains, made thousands of people homeless and destroyed a huge amount of infrastructures [30]. From that period the embankments were retired several times due to tidal surge, climatic change, river bank erosion. Then bank protection are repeatedly required during the monsoon and post-monsoon season. In coastal region including research area most of the rivers were trained by established Water Polder (earthen embankment), which developed by BWDB. A polder is defined as a level area which has originally been subject permanently or seasonally to a high water level and is separated from the surrounding hydrological regime to be able to control water levels and prevent the intrusion of tidal flood water, where shrimp and paddy culture are practiced [18, 24]. In this area Polder was established especially for protecting community from severe bank erosion due to huge tidal surge. Studies were undertaken for effectiveness of river training structure on protection measure, hydraulic and hydrological concern and environmental aspect [21], however excluding the rivers of coastal district. Yet from the construction of these structures, several renovation work accomplished for severe erosion prone bank side, still did not assessed the usefulness on the basis of river process and socio-economic benefit. Shriwastava and Sharmar [25] stated, in present context, it is essential to assess the conventional river training methods practically for respective areas where thousands of kilometres of erosion-affected stream bank-line are awaiting for managing action. This paper reported on the usefulness of present river training structures and their perspectives on the basis of hydro-morphology and qualitative socio-economic benefits of inhabitants in Patuakhali District.

2. MATERIAL AND METHODS

The objective of this research was to assess the usefulness of existing river training structure in qualitative benefits and present operational status. Assessments were taken on technical point of view and economic-environmental aspects accomplishing spot visit, face to face interview and focus group discussion method during July-Sep in 2015. These tools were applied to evaluated protection measure, structural failure, river morphology, present status and qualitative benefits.

2.1 The research area

The research area (Patuakhali district) is situated at 22° 21'15"North latitude and 90° 20' 5"E longitude. The area is surrounded by different main rivers of Patuakhali district lies on southern coastal zone in west Barguna district, North & East surrounded by Barisal and Vola district and in south the Bay of Bengal. The main rivers which pass through the area are Payra, Lohalia, Andharmanik, Lawkati, Kajal, Ramnabad, Tetulia and Agunmukha etc. Most of the rivers are distributary channels originated from the Ganges and drop into the Bay of Bengal. The rivers flows through the Patuakhali district are close to the Bay of Bengal which is tidal and navigable all over the year. The tides are influenced by the attraction of the sun and moon with sea water [7]. The rivers were trained to maintain the morphological equilibrium for social protection where buildup numbers of Polder by constructing coastal embankment. Three categories of training structure were selected from 10 (ten) different polder and sub project area which was implemented by Bangladesh Water Development Board (BWDB) as shown in Fig.1 as well as describe in Table 1. Most of the river training structure was practiced for controlling bank erosion for sustainable river management and for socio-economic benefits and environmental ecological aspect. Different categories of bank protection practices were evaluated in context of sustainability, erosion prone and their existing situation of the study area.



Study location= ▽

Source: BWDB, Patuakhali Operation & Management division office's publication (Hard copy) and [\[http://mapofbangladesh.blogspot.com/2011/09/patuakhali-district.html\]](http://mapofbangladesh.blogspot.com/2011/09/patuakhali-district.html)

Fig.1 A map of Patuakhali District (left side) including the study area showing main rivers and different study location (right side) besides the rivers.

Table 1. Selection of different river training structures at different location of the research area

Category of structures	Name of river	Location name
1. Earth embankment	-Payra river	Maximum Polder and coastal embankment
	-Lawkati river	project area, such as:
		(i) Mirzagonj Rampura project-Payra river,
		(ii) Subidkhali Madhobkhali coastal Embankment,
		Muradia kalagachia coastal embankment and
		Dumki Lawkati embankment, etc.
2. Revetment		
i) with cement concrete (CC) block	-Payra river	(i) Lebukhali Feri Ghat point,
	-Lohalia river,	(ii) Patuakhali town protection work 2
	-Andharmanik river	(iii) Khepupara Bandar and town protection work.
ii) with Geo-bag/sand-cement bag	-Lawkati river	Patuakhali town protection work 1
iii) with stone	-Lohalia river	Patuakhali town protection work 2
3. Bandals	-Kajal river	Galachipa

Source: Spot visit.

2.2 Data collection

In order to document and assess the usefulness of river training structure and its present status in Patuakhali district, data were collected by visiting at 10 (ten) main river bank protection site of different polder located beside the river. A worksheet has been prepared to carry out the questioner survey and social inquiries on particular river training practice and bank protection measures. During study period, we established 5 (five) groups together with 8 people per group in each location for measurement of different level of risk of these training structures on the basis of some key point issue such as: spot observation, river flow situation, inhabitant's previous observation based opinion and length of the erosion-protection point. The indigenous knowledge of local natives was used and interprets in technical point view that might be a good tool for understanding the river bank erosion risks and effectiveness of these training structures as evaluated the effectiveness of watershed management practices by collecting data through semi-structured interview, focus group discussion,

field observations and field measurements [28] and severity of flood embankment situation by field visit and questioner survey [10]. Formerly, we had assigned score based on these key points issue for different level of risk such as: low risk level (1.0-2.5), medium risk level (2.6-4.5) and High risk level (4.6-6.0) from individual's opinion. Thus, around 40 inhabitants participated in this group discussion to give their opinion to complete the worksheet in each location. The status and usefulness of all protection structures were measured on the basis of five points such as (i) stable time after construction and renovation, (ii) number of erosion per year, (iii) number of qualitative benefits due to protection measures, (iv) number of damages due to erosion and (v) spot observation. Similarly, several key components such as historical data, upper storage of water reservoir, flood damage filed survey, flood mitigation option etc. was considered for assess flood damage risk status [9]. The discussion upon these points, decision was taken about the present status of these training structures and assigned score 1 (one) for each point collectively as unstable (<1.0), short time stable (1.0-2.0), stable due to maintenance (>2.0-3.0), moderately stable (>3.0-4.0) and stable (>4.0-5.0). The author also visited and collected some information from Bangladesh Water Development Board Patuakhali Operation and Management division branch office. Information also collected from some secondary sources such as books, reports, journals etc. The author discussed on various issues of river training structure and their socio-economic impact on locality with different researchers and specialists of this research field.

3. RESULTS AND DISCUSSION

3.1 Features of training structures

There were three categories of river training structure such as earth embankment, revetment (with CC block, stone, sand-cement and geo-bag) and Bandals were found in the research area. Most of the river was trained by establishing Polder [18] as similar to earthen embankment. The details of main rivers of this research area (ten locations) under training including numbers of Polder and name of these locations are described in **Table 2**.

172 **Table 2.** Main rivers of Patuakhali district under trained by constructing numbers of Polder.

Name of main River	Polder name/Number	Length of bank protection/embankment/revetment with CC block/ Geo-bag/sand-cement bag (Km)	Name of location
Payra	Itbaria-lebukhali sp.*	0.713	Lebukhali
Payra	Mirzagonj Rampura sp.*	45.60	Mirzagonj Rampura
Lohalia	43/2D	0.625	Patuakhali Town 1
Andharmanik	54/A	0.427	Khepupara Bandar protection
Andharmanik	43/1B, 46	22.77	Kalapara
Lawkati	43/2H	0.842	Patuakhali Town 2
Kajal	55/1	46.16	Galachipa
Ramnabad	50/51	48.00	Baherchar
Tetulia river	55/2 E	70.00	Bauphal
Tetulia river	55/2D	65.60	Dasmina

173 * sp-sub project, Source: BWDB, Patuakhali Operation & Management division office publication and
 174 [4, 5]

175

176 Earth embankment is a ridge or bund built especially by earth, or mixture of earth and rock to confined
 177 river and flood water or to construct highway, railway, canal etc. This type of earthen river training
 178 embankment constructed and practiced in Bangladesh [2], especially in research area for protecting
 179 people's lives, homes, agriculture and infrastructures from tidal flood. The embankments features and
 180 purposes were depends on nature under a variety of circumstances. This structure was also designed
 181 to control or prevent tidal surge, high water flooding. The embankment built to prevent flooding of low-
 182 lying land is also called levee or dyke which constructed along the riverbank and maintain certain
 183 distance from the river to retain floodwater. Almost flat and low land elevations (from the mean sea
 184 level) are interspersed with a dense network of semi-diurnal tidal channels carrying saline water that
 185 make the area none-suitable for agricultural production. Firstly people started constructing Polders by
 186 raising the banks of tidal channels thus preventing entry of saline tidal prism on low-lying area and
 187 helping inhabitants to cultivate crops. The Polders were formed into a closed area by earthen
 188 embankment surrounding the depressions zone (keeping the main tidal channels outside of the
 189 Polder) and maintain connection with main channel by constructing sluice gated hydraulic structures
 190 on an intersecting points (meeting points of embankment and secondary tidal channels) [2]. Most of

the monsoon time, different places of Bangladesh have witnessed of unprecedented distractions and damages of several embankments due to tidal flood, cyclone, tidal surge etc. For that reason almost two-thirds area of the country went under water every year and thus broken of embankments and relevant distractions were caused massive damages of properties [10]. The earthen embankments of the research area represent the identical role as well as all over the country. Some places of this structures constructed of revetment using cement concrete (CC) block, geo or sand-cement bag, or stone etc. regarding to level of erosion risk. Recently bandals (made by bamboo or relevant wood) were used to construction of groin like structure along the river side to prevent bank erosion which has demonstrated worthy result.

3.2 Structural failure mechanism and risk measure

In present circumstances, the river management authorities have necessary to understand the mechanism of bank failure. In fluvial systems there are three ways river bank generally fail such as: (i) hydraulic forces remove erodible bed or bank material, (ii) geotechnical instabilities result in bank failure, and (iii) a combination of hydraulic and geotechnical forces causes failure [8]. Some river side of this research area are became vulnerable condition of erosion due to above mention reason and still these area are under different level of risk though dissimilar protection measure has been taken. The details of bank erosion and protection measures under different level of risk at different location of main rivers of this study area are described in **Table 3**. According to the individual's opinion we found different locations at different river side were noticed under different level of risk in which constructed the protection measure. The risk level scores ranged from 1 to 6 with an average of 2.71 represented all the training structures under low to medium level of risk except Payra river side at Lbukhali Feri Ghat point. Adjacent to Lebukhali Feri Ghat and several other point including about 1.74 km concrete block revetment was failed due to high flow velocity directly struck on river bank and return flow creates local scouring near bank which caused massive failure as view in photographic Fig. 2 and represented under high level of risk averages 5.22 as shown in Fig. 3a. The high velocity return current reflects by emerging char at opposite bank of Payra river. For that reason generation of high expulsion around the revetment also causes of failure. The both bank side of Payra River at Lebukhali Feri-Ghat point is more vulnerable as comparing from others points. Cement concrete (CC) block revetment possess this area safe from tidal current temporarily. The revetment with cement concrete (CC) block including around 1.8 km bank protection work from erosion due to moderate

velocity tidal current under low risk level at Patuakhali town protection point 2 and Khepupara Bandar & town protection point. Revetments with geo or sand-cement bag at Lawkati river bank side for Patuakhali town protection point 1 are the defensive structure and relaying under medium level of risk. In this section of the river flowing straight and this protection measure can save the bank from straight flow current. The main purpose of these structures was to modify the struck flow velocity on the river bank and protect from erosion. The earthen embankment used as river bank protection structure of Baherchar point, Bauphal point, Dashmina point and Southern Galachipa point was found under low risk level where as bank protection by bandals at Galachipa point was found under medium level of risk as shown in **Fig. 3 a & b**. Therefore, although the maximum bank protection structures condition under low to medium risk level however, all are effective in purposes as several researchers evaluated using different techniques. Sarker and Akter [22] evaluated bank protection structure of Jamuna river and stated as effective, minor damage, major damage, minor damage but effective etc. by historical data and experience from several case study. Revetment with Jute Geotextile was found as effective after three times investigation of river bank protection measure [13].

Table 3 Persons perception showed present status of river bank under different level of risk.

Name of River	Bank failure	Location Name	Level of risk
Payra,	Sever	Lebukhali Feri Ghat point	High
Payra,	Moderate	Mirzagonj Rampura point	Medium-Low
Lohalia,	Moderate	Patuakhali town protection 1	Medium
Andharmanik,	Moderate	Khepupara Bandar protection	Low
Lawkati	Moderate	Patuakhali town protection 2	Low
Kajal,	Moderate	Galachipa point	Medium
Ramnabad,	Moderate	Baherchar point	Low
Tetulia river	Moderate	Bauphal point	Low
Tetulia river	Moderate	Dashmina point	Low
Agunmukha	Moderate	Southern Galachipa point	Low

Source: Spot visit & group discussion.



Fig.2. Photographic view showed the severe erosion prone area at Lebukhali Point of Payra River.

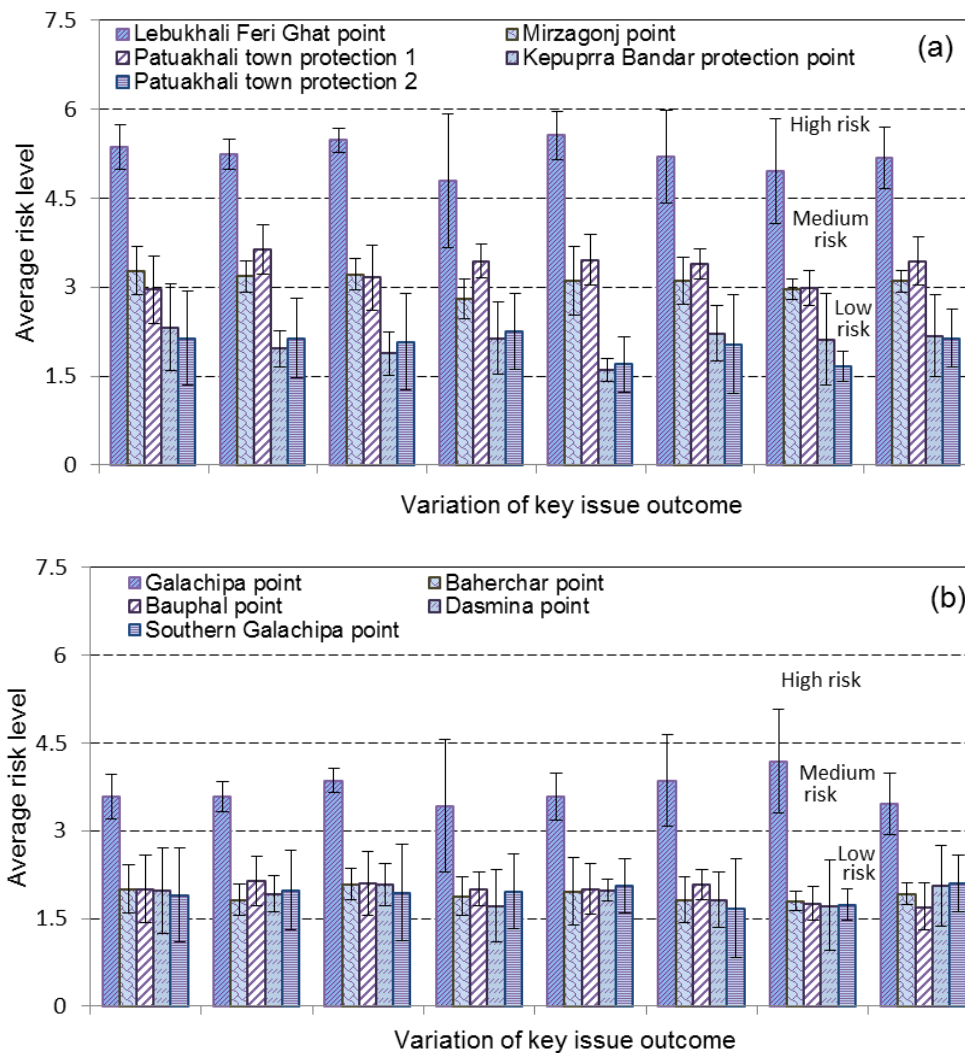


Fig. 3 (a & b). Bar chart shows the variation of different level of risk in groups at 10 (ten) different location of bank protection practices

3.3 River morphology and Status of protection measure

River morphology is the variations of river shape in cross-section and changes of flow direction and pattern due to sediment deposition and transportation processes, which can be segmented into different branches that are often interrelated to each other. The areas of morphology are including overland flow, channel flow, channel network distribution and diversion, stream channels with flow characteristics, stream stages, stream discharge, drainage systems, horizontal profiling and profile development, stream erosion and transportation etc. [23]. It affects on river width, depth, slope, flow velocity, discharge, flow resistance, sediment size and sediment load [15]. Maximum of the floodplains including the research area of Bangladesh have been formed by the settlement of sediment that's carried by rivers. A comparison study was done by Zhang et al. [29] with conventional revetments and spur dykes. The flow structure and bed morphology around the Sirajganj Hardpoint and Betil/Enayetpur spur dykes of Jamuna River, found much more complex due to the complex flow and bed conditions. In this study area the tidal flow carry high sediment load and recent formation of bed load in high velocity. For that reason, rivers of this area are highly dynamic in nature. Hydrological and climatic parameters also would make the rivers more vulnerable as well as unpredictable. Morphology of these rivers was being subsequent impacts on floodplain dwellers [11], which were likewise under observation during study period. The status and usefulness of all protection structure were measured by fixing criteria as designated method as shown in **Fig. 4** and also described with consequences in **Table 4**. All the protection structures were found from moderately stable to stable due to maintenance though morphological changes of river is different at different location. The tidal flow velocity and depth of bottom scouring in all rivers are very high. Payra River is more vulnerable due to erosion prone because of river flows directly hit on this bank reflect the current and producing meandering channel. Though revetment with CC block is moderately stable structure according to the outcome, however after construction of this revetment, this area is free from short time risk. The revetments with geo-bag and sand-cement bag at Patuakhali town protection bank are defending strongly form high velocity flow hit. As per local people perception, the Bandalling (made by wood) savings temporarily their valuable agricultural land form erosion at Kajal river side, Galachipa. This structure is a simple alternative low cost conventional structure made by bamboo or wood. Bandal structures are physically considered as combined structures of permeable spur dykes and pile dykes [29]. The bandals are positioned at an angle with main flow. When surface flow forced on the face of

structure, it reduced velocity due to obstacle and flow through the bottom direction [19]. These are the characteristics of this structure are for the control velocity of water and sediment flow [20]. As a result sand bar or char land were formed along the river bank side due to sedimentation as shown in Fig.5. However, the structures are required to keep under continuous observation and renovation timely necessarily in any situation.

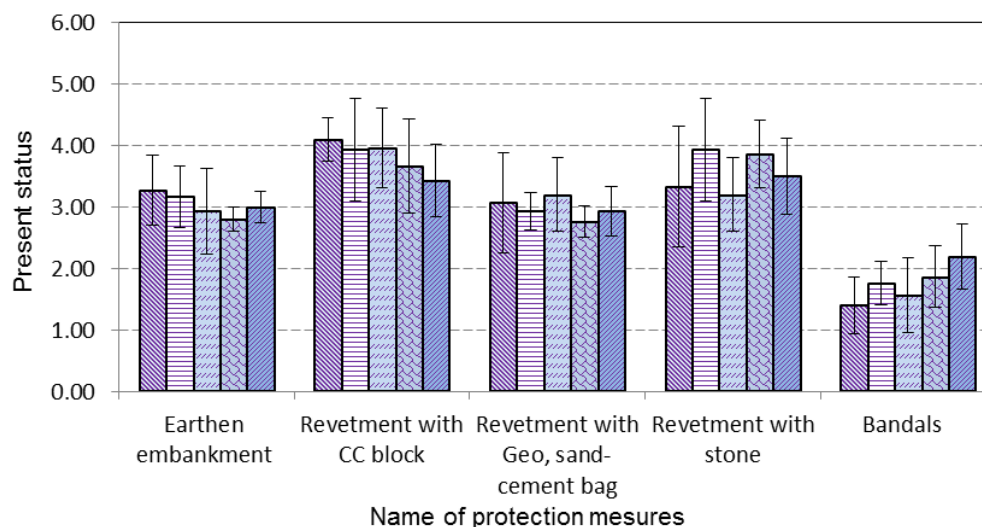


Fig. 4. Present status of protection measures found at different location based on stable = >4.0-5.0, moderate stable = >3.0-4.0, stable due to maintenance = >2.0-3.0 and short time stable = 1.0-2.0)

Table 4. Status, consequences and usefulness of protection measures

Category of structures	Present Status	Consequences and usefulness of protection measure
Earthen embankment	Stable due to maintenance	By construction of earthen embankment protect tidal flow from entering into locality and reduced erosion due to minimized velocity of struck. Save agricultural land. The embankment established as local road for good communication.
Revetment with cement concrete (CC) block	Moderately stable	Flow hits on revetment and divert it to channel center. It reduces erosion due to turbulence flow can protest at the base of the structure and reflect slide down.

Revetment with Geo-bag/sand-cement bag	Stable due to maintenance	Flow diverted due to protection measure and resistance grows from erosion.
Revetment with stone	Moderately stable	Flow diverted into multi-angle (zikzak) stone reduced energy and erosion.
Bandals	Short time stable	Velocity of water reduced and flow diverted. Sand bar formed near bank finally reduce erosion.



Fig.5. Photographic view of bandaling structure used for controlling bank erosion at Kajal river side in Galacipa.

3.4 Benefit of protection structures

These river training structures is expected to lead to increase of benefits and development for stakeholders as well as for locality of the research area. Benefits of human lives saved are impossible to quantify and are not included in the economic analysis. However, it is estimated that about 140,000 people were died in the coastal district of Bangladesh including the study area during the 1991 cyclone [27]. The cyclone devastation with tidal surge struck, destroyed the river bank and sea water enter into locality with several meter height that caused of huge death. After construction and renovation of these river training structures, it was helped to save lives and properties and bringing social benefits by reduction of devastating damages as stated by Heidari [9]. According to focus group discussion some qualitative benefits were evaluated as described in Table 5.

Table 5. Qualitative benefits after construction of river training structure

Category	Post-Observations and Qualitative benefits
Human lives	Fewer human lives lost during cyclones, storm surges and tidal surges

Property and protection	Less property destroyed during cyclones, storm surges, tidal surges that complementary work improve drainage leading to increased agricultural production.
Production	Embankments would protect a gross area from cyclone and tidal surge leading to increased agriculture and fish production.
Afforestation	Afforestation for cyclone protection and embankment maintenance would have ancillary benefits.
Employment	Embankment would generate additional employment during construction and through increased agricultural production.
Damage reduction	Construction of river training structures reduced the damages due to adverse erosion by tidal surges as the benefits.
Others	River training work would give unquantified benefits like, savings on emergency relief, environmental benefits etc.

Source: Spot visit, interview & focus group discussion

4. CONCLUSION

Most of the rivers in Patuakhali District were trained with developing Polder by constructing coastal embankment. The flow velocity with tidal surge creates turbulence in all major rivers results in scour occurs at the bank that getting at risk especially during high tidal current. The structures were able to protect the bank erosion provisionally while a percentage of bank materials are moderately fragile. All the structures are technically suitable based on local circumstances and moderately stable due to maintenance. The embankment materials of research area are primarily consists of clay with a small amount of silt and sand. The clay particles of these embankment materials are stickier which can tolerate tidal struck. In the view of environmental ecological and social context of the study area the bandal structure is novel invention and can contribute in coastal embankment protection. The structures has good social acceptance which can makes it further development and renovation and also need to do continuous management for its sustainability.

CONSENT

Not Applicable

344 ETHICAL APPROVAL

345 Not Applicable

346

347 REFERENCES

- 348 [1] Banglapedia. National Encyclopedia. The People Republic of Bangladesh. 2012a; Accessed
349 05 August 2016. Available: <http://en.banglapedia.org/index.php?title=River>.
- 350 [2] Banglapedia. National Encyclopedia. The People Republic of Bangladesh. 2012b; Accessed, 05
351 August 2016. Available: <http://en.banglapedia.org/index.php?title=Embankment>.
- 352 [3] Best JL, Ashworth PJ, Sarker MH, Roden JE. The Brahmaputra-Jamuna River Bangladesh. In
353 Large rivers: geomorphology and management. Wiley & Sons Ltd, Chichester, 2007: 395-430.
354 <http://onlinelibrary.wiley.com/doi/10.1002/9780470723722.ch19/summary>
- 355 [4] BWDB (Bangladesh Water Development Board). Final Report. Ministry of Water Resources. The
356 People's Republic of. Bangladesh. Printed and Published by BWDB. Oct. 2010: 1-134.
357 <http://www.bwdb.gov.bd/archive/pdf/249.pdf>
- 358 [5] BWDB (Bangladesh Water Development Board). Final Report. Coastal Embankment
359 Improvement Project, Phase-I (CEIP-I). Ministry of Water Resources. The People's Republic of.
360 Bangladesh. Printed and Published by BWDB. June, 2013; 1(Main Report): 1-164. Available:
361 <http://www.bwdb.gov.bd/archive/pdf/364.pdf>
- 362 [6] Chowdhury RK, Maruf BU, Chowdhury AI. Climate change would intensify river erosion in
363 Bangladesh, Impact of climate change in Bangladesh, Dhaka. 2007. Available:
364 <http://www.equitybd.org/newsletter/issue/02/5.pdf>
- 365 [7] Dronkers JJ. Tidal computation in rivers and coastal waters. North-Holland Publishing Company,
366 Amsterdam. 1964: 381. Available: <http://www.jstor.org/stable/40605488>
- 367 [8] Fischenich JC. Channel Erosion Analysis and Control. In: Woessmer and Potts (eds.)
368 Proceedings Headwaters Hydrology. Montana Section, American Water Resources Association,
369 Bethesda, Maryland. June, 23-27, 1989: 101-103.
- 370 [9] Heidari A. Structural master plan of flood mitigation measures. Nat. Hazards Earth Syst. Sci.,
371 2009; 9: 61-75. Available: <http://www.nat-hazards-earth-syst-sci.net/9/61/2009/>
- 372 [10] Hossain MZ, Sakai T. Severity of Flood Embankments in Bangladesh and its Remedial
373 Approach. Agricultural Engineering International: the CIGR E-Journal. 2008; Manuscript LW 08

- 374 004.Vol. X. May, 2008.
 375 Available:<http://cigrjournal.org/index.php/Ejournal/article/viewFile/1229/1086>
- 376 [11] Hossain S, Rahman M, Nusrat F, Rahman R, Anisha NF. Effects of Climate Change on River
 377 Morphology in Bangladesh and a Morphological Assessment of Sitalakhya River. Journal of
 378 River Research Institute (RRI). Dec, 2014: 1-13. Available:
 379 [https://www.researchgate.net/search/Search.html?query=river%20morphology%20bangladesh&t](https://www.researchgate.net/search/Search.html?query=river%20morphology%20bangladesh&type=publication)
 380 [ype=publication](https://www.researchgate.net/search/Search.html?query=river%20morphology%20bangladesh&type=publication)
- 381 [12] Imran J. Can river training benefit us? The daily Star, The National Newspaper in Bangladesh,
 382 Published Saturday, September 4, 2009. Accessed, 05 August 2016. Available:
 383 <http://www.thedailystar.net/news-detail-104402>
- 384 [13] Islam MS, Khan AJ, Sddique A, Kabir R, Nasrin S. Performance evaluation of river bank
 385 protection using jute geotextiles. National Seminar on Jute Geo-textiles, Organized by Jute
 386 Diversification Promotion Centre (JDPC), May, 2014. Dhaka, Bangladesh
- 387 [14] Lane EW. The importance of fluvial morphology in hydraulic engineering.
 388 American Society of Civil Engineers. US. 1955.
- 389 [15] Leopold LB, Wolman MG, Miller JP. Fluvial processes in geomorphology, A book of W. H.
 390 Freeman and Company, San Francisco, California. 1964.
- 391 [16] Madej MA, Weaver WE, Hagans DK. Analysis of bank erosion on the Merced River: Yosemite
 392 Valley, Yosemite National Park, California, USA, Environment Management. 1994; 18(2): 235-
 393 250. [doi:10.1007/BF02393764](https://doi.org/10.1007/BF02393764)
- 394 [17] PieÂgay H, Bravard JP. The reactions of a mediterranean riparian forest to a major hydrological
 395 event, the 1 in 400 year in the OuveÂze River, DroÃme-Vaucluse, France, Earth Surface
 396 Processes and Landforms. 1997; 22(1): 31-43.
- 397 [18] Polder of the World. Final Report. International Symposium. The Netherlands, 1983: 15-23.
- 398 [19] Rahman MM, Nakagawa H, Ishigaki T, Khaleduzzaman ATM. Channel stabilization using
 399 bandalling. A published article of Annuals of Disaster Prevention Research Institute, Kyoto
 400 University, 2003; 46 B: 613-618. Available: [http://repository.kulib.kyoto-](http://repository.kulib.kyoto-u.ac.jp/dspace/bitstream/2433/129127/1/a46b0t55.pdf)
 401 [u.ac.jp/dspace/bitstream/2433/129127/1/a46b0t55.pdf](http://repository.kulib.kyoto-u.ac.jp/dspace/bitstream/2433/129127/1/a46b0t55.pdf)
- 402 [20] Rahman MM, Nakagawa H, Khaleduzzaman ATM, Ishigaki T, Muto Y. One the formation of
 403 stable river course. A published article of Annuals of Disaster Prevention Research Institute,

- 404 Kyoto University, 2004; 47B: 601-616. Available:
405 <https://www.researchgate.net/publication/47528186>
- 406 [21] Rahman MM, Arifur RM, Munsur R (2012) Effectiveness of River Training Structures in
407 Bangladesh. ICSE6 Paris - August 27-31, 2012: 935-940. Available: [http://scour-and-](http://scour-and-erosion.baw.de/icse6-cd/data/articles/000066.pdf)
408 [erosion.baw.de/icse6-cd/data/articles/000066.pdf](http://scour-and-erosion.baw.de/icse6-cd/data/articles/000066.pdf)
- 409 [22] Sarker MH, Akter J. River bank protection measures in the Brahmaputra-Jamuna
410 River:Bangladesh Experience. International Seminar on 'River, Society and Sustainable
411 Development, Dibrugarh University, India. May, 2011.
- 412 [23] Schumm SA. The fluvial system. A Book of classic geomorphology literature. John Wiley & Sons
413 Inc. The Blackburn Press. New York. November, 1977. Geol. J., 13: iii. Available:
414 <http://www.blackburnpress.com/fluvialsystem.html>
- 415 [24] Segeren WA, Schultz E, Van-Giersbergen WJM, Leemhuis-Stout JM, Luijendijk J, Wolters W.
416 Polders of the World: Papers international Symposium. Lelystad, the Netherlands. 1982.
- 417 [25] Shriwastava A, Sharmar N. Investigation of RCC Jack Jetty as a Cost Effective River Training
418 Structure. International Conference on Agricultural, Environmental and Biological Sciences,
419 AEBS-2014. Phuket, Thailand. April, 24-25, 2014: 42-46. Available:
420 <https://www.researchgate.net/publication/269694387>
- 421 [26] Tamrakar NK, Bajrachrya R, Sapkota S, Thapa I, Paudel PN, Tamang NB. Riverbank erosion
422 potential and channel stability status of the Kodku River, southern Kathmandu Basin, Central
423 Nepal. Bulletin of the Department of Geology, Tribhuvan University, Kathmandu, Nepal, 2014;
424 17: 1-41. Available: <https://www.researchgate.net/publication/279209423>
- 425 [27] The World Bank (WB). Coastal Embankment Rehabilitation Project. Staff Appraisal Report.
426 Bangladesh. Report No. 15039-BD. October, 1995: 43. Available: [http://www-](http://www-wds.worldbank.org/external/default/WDSPContentServer/WDSP/IB/1995/10/16/000009265_3961008063725/Rendered/PDF/multi0page.pdf)
427 [wds.worldbank.org/external/default/WDSPContentServer/WDSP/IB/1995/10/16/000009265_39610](http://www-wds.worldbank.org/external/default/WDSPContentServer/WDSP/IB/1995/10/16/000009265_3961008063725/Rendered/PDF/multi0page.pdf)
428 [08063725/Rendered/PDF/multi0page.pdf](http://www-wds.worldbank.org/external/default/WDSPContentServer/WDSP/IB/1995/10/16/000009265_3961008063725/Rendered/PDF/multi0page.pdf)
- 429 [28] Tiki L, Kewessa G, Wudneh A. Effectiveness of watershed management interventions in Goba
430 district, southeastern Ethiopia. Int. J. Agric. Sci., 2016; 6 (9): 1133-1140.
- 431 [29] Zhang H, Nakagawa H, Baba Y, Kawaike K, Teraguchi H. Three-dimensional flow around
432 Bandal-like structure. Annual Journal of Hydraulic Engineering, JSCE, 2010; 54: 175-180.
433 Available: <http://www.cc.kochi-u.ac.jp/~zhang/pdf/J-2010AJHE.pdf>

- 434 [30] Zhang H, Nakagawa H, Baba Y, Kawaike K, Rahman MM, Uddin MN. Hydraulic and
435 Morphological Consequences of Bank Protection Measures along the Jamuna River,
436 Bangladesh. *Annals of Disas. Prev. Res. Inst., Kyoto Univ.* 2011; 54 B: 477-496. Available:
437 <https://www.researchgate.net/publication/266353225>.