MORPHOLOGICAL STABILITY OF A DREDGED CHANNEL FOR RIVER TRAINING: A CASE STUDY ALONG THE BRAIDED JAMUNA RIVER

MD. MOSIUR RAHMAN

বাংলাদেশ প্রকৌশল বিশ্ববিদ্যালয়
নং 113265
তাং 12.11.14
লাইব্রেরী, ঢাকা

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INSTITUTE OF WATER AND FLOOD MANAGEMENT
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Morphological Stability of a Dredged Channel for River Training: A Case Study along the Braided Jamuna River

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Md. Mosiur Rahman

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CANDIDATE'S DECLARATION

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

....

Md. Mosiur Rahman

Roll No. 1009282006

Session: October 2009

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

INSTITUTE OF WATER AND FLOOD MANAGEMENT

The thesis titled **'Morphological stability of a dredged channel for river training: A case study along the braided Jamuna River'** submitted by Md. Mosiur Rahman, Roll No. 1009282006, Session: October 2009, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of M.Sc. in Water Resources Development on 18th November, 2013.

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Dhaka-1206

Dedicated to

My Family

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ABSTRACT

The erosion and shifting of river courses, loss of land, especially along the Jamuna river have long been recognized as a national problem that affects a sizable population in Bangladesh. To mitigate the river bank erosion BWDB has initiated a 20 km capital dredging on the River Jamuna as pilot basis in order to guide the flow to reduce the risk of failure of Sirajganj Hard Point and right guide bundh of the Bangabandhu Bridge. This study would be useful to assess the role of capital dredging in comprehensive river management plan as well as the morphological stability of an artificial dredged channel along the braided Jamuna river of Bangladesh. The sustainability of the dredged channel was assessed by analyzing the time-series satellite images, cross-section comparison, sediment concentration and depth average velocity. Geo-referenced satellite image of ASTER and IRS LISS from 2007 to 2012 has been superimposed to assess the sand bar movement. During 2007 to 2012, lateral movement of Sandbar-1 (upstream of Sirajganj Hardpoint) ranges from 800m to 1870m whereas for Sanbar-2 (downstream of Sirajganj Hardpoint) ranges from 560m to 1060m. At the same time, the longitudinal movement of Sandbar-1 ranges from 150m to 600m whereas for Sandbar-2 ranges from 300m to 1400m. It is observed that, the channel is developing very fast along the western bank through deviation of flow towards the river bank. It's is also observed that the rate of bar translation is high and it may cause the siltation of the dredged channel. Comparison of cross-section indicates that there is no significant positive impact of dredging has observed near Sirajganj Hardpoint area as well as the downstream of Banghabhandhu Bridge. It is also observed that the rate of siltation is higher, where the dredging alignment passes through the existing char. It was happening, because the hydraulic condition around the dredged area as well as upstream river morphology remain favorable for the siltation on the existing char. Analysis of observed data indicates that, more than 1.75 m/s flow velocity persists during the peaks which covering the entire Sirajganj Hardpoint area and it persists from mid of May to September. Analysis of sediment concentration and depth average velocity indicates that sediment concentration at particular depth and velocity plays an important role in the erosion or deposition process along the study reach. It is found that at a particular point under or over sediment concentration with respect to the sediment transport capacity cause either erosion or deposition. The major finding of this study is that the dredging of a braided river would not be a sustainable solution without changing upstream river morphology as well as hydraulic conditions. It is also observed that, if the dredging alignment passes through the existing channel not over the char area, the dredged channel would be more sustainable.

ABBREVIATIONS

ADCP	Acoustic Doppler Current Profiler
BBA	Bangladesh Bridge Authority
BBS	Bangladesh Bureau Statistics
BRE	Brahmaputra Right Embankment
BI	Braiding Index
BM	Bench Mark
BUET	Bangladesh University of Engineering and Technology
BWDB	Bangladesh Water Development Board
CEGIS	Center for Environmental and Geographic Information Services
DGPS	Differential Global Positioning System
DHI	Delft Hydraulic Institute
EC	Eastern Channel
EGB	East Guide bank
FAP	Flood Action Plan
G&D	Gauge and Discharge
GPS	Global Positioning System
GCPs	Ground Control Points
GIS	Geographic Information System
HFL	High Flood Level
IWFM	Institute of Water and Flood Management
IWM	Institute of Water Modelling
KII	Key Informant Interview
PRA	Participatory Rural Appraisal
PWD	Public Works Datum
RTW	River Training Works
SHP	Sirajganj Hard Point
TBM	Temporary Bench Mark
WC	Western Channel
WGB	West Guide Bank

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নং 113265
তাং 12.11.14

CHAPTER ONE

INTRODUCTION

1.1 Background and present state of the problem

Bangladesh is a delta formed by the alluvial deposits of the three major rivers: the Ganges, the Brahmaputra and the Meghna. There are 311 rivers in Bangladesh of which 53 rivers come from India and other 4 rivers come from Myanmar. The Ganges, the Brahmaputra and the Meghna of these three major river systems drain around 1,350 billion cubic meter of discharge annually from a total catchment area around 1.72 million sq.km through Bangladesh into the Bay of Bengal. Therefore the role of 311 rivers are mainly bring flow season for various purposes. The major rivers of Bangladesh also carry huge sediment load from the large catchments a resulting to about 1.0 to 1.1 billion tons annually. The Jamuna is one of the largest braided rivers in the world. The changing planform of banks and sandbar of the river not only cause suffering to the people living along its course but also cause national losses damaging cultivated land, settlements, commercial centers and infrastructures. Therefore, the better understanding of the behavior of the river would be useful to mitigate losses by river erosion.

For a scientific and rational approach to different river problems and proper planning and design of water resources projects as well as understanding of the morphology and behavior of the river is a pre-requisite. Morphology of river is a field of science which deals with the change of river plan form and cross-sections due to sedimentation and erosion. In this field, dynamics of flow and sediment transport are the principal elements. The morphological studies play an important role in planning, designing and maintaining river engineering structures. Due to carrying huge sediment loads with low gradient, riverbed aggradations is most pronounced for the major rivers of Bangladesh. The morphology of the major rivers is very dynamic in nature and frequent human interventions caused the rapid declining the behavior of river morphology. These metamorphoses have been changing the flood regimes, agricultural practices, floodplain ecosystem and navigation. The Old Brahmaputra River was navigable for steamers only about 60 years ago, but presently it is an abandoned channel. This picture is true for many other distributaries of the Ganges and Meghna Rivers. Human interventions without considering the river morphology often caused the aggradations and reduced navigability as well as the water carrying capacity of rivers.

A comprehensive study of capital dredging and sustainable river management in Bangladesh has been formulated in water sectors to cope with the challenges of bank erosion, sediment transport, flood control and navigation etc. (BWDB-IWM, 2013). The main objectives of these studies was to advise a management plan of major rivers, tributaries and distributaries for mitigation of flood and erosion management, to improve navigability and to argument dry season flow in the distributaries considering capital dredging and river training works and other interventions. This strategy and action plan will identify the conceptual framework of capital dredging for flood and erosion management, explore financial options and formulate options for implementation. The study will be composed of capital dredging, river training works, sustainable maintenance dredging module, spoil management, channelization of the main rivers, afforestation, navigation, land development, fisheries development, environmental management plan and monitoring etc.

The erosion and shifting of river courses, loss of land, especially along the Jamuna river have long been recognized as a natural problem that affects a sizable population in Bangladesh. The overall width of the river exhibits an increasing trend, especially at the upstream part of the Jamuna River. To mitigate the river bank erosion, government has taken a decision to immediately implement capital dredging in the Jamuna River in a pilot basis. Total length of the pilot dredging is about 20 km from upstream of Sirajgonj hard point to downstream of Banghabandhu Bridge near Dhaleswari Offtake. The main purpose of this pilot capital dredging is to divert the flow from the west channel into a mid channel to reduce the risk of failure of Sirajganj Hard Point and to guide the flow along the middle of the existing char through the Bangabandhu Bridge to near Dhaleswari Offtake. It is expected to reduce the risk of riverbed scour along the Sirajganj Hard Point and also reduce the erosion of west guide bund of Bangabandhu Bridge. To achieve the above target through pilot dredging, the analysis of sustainability of the dredged channel is very important.

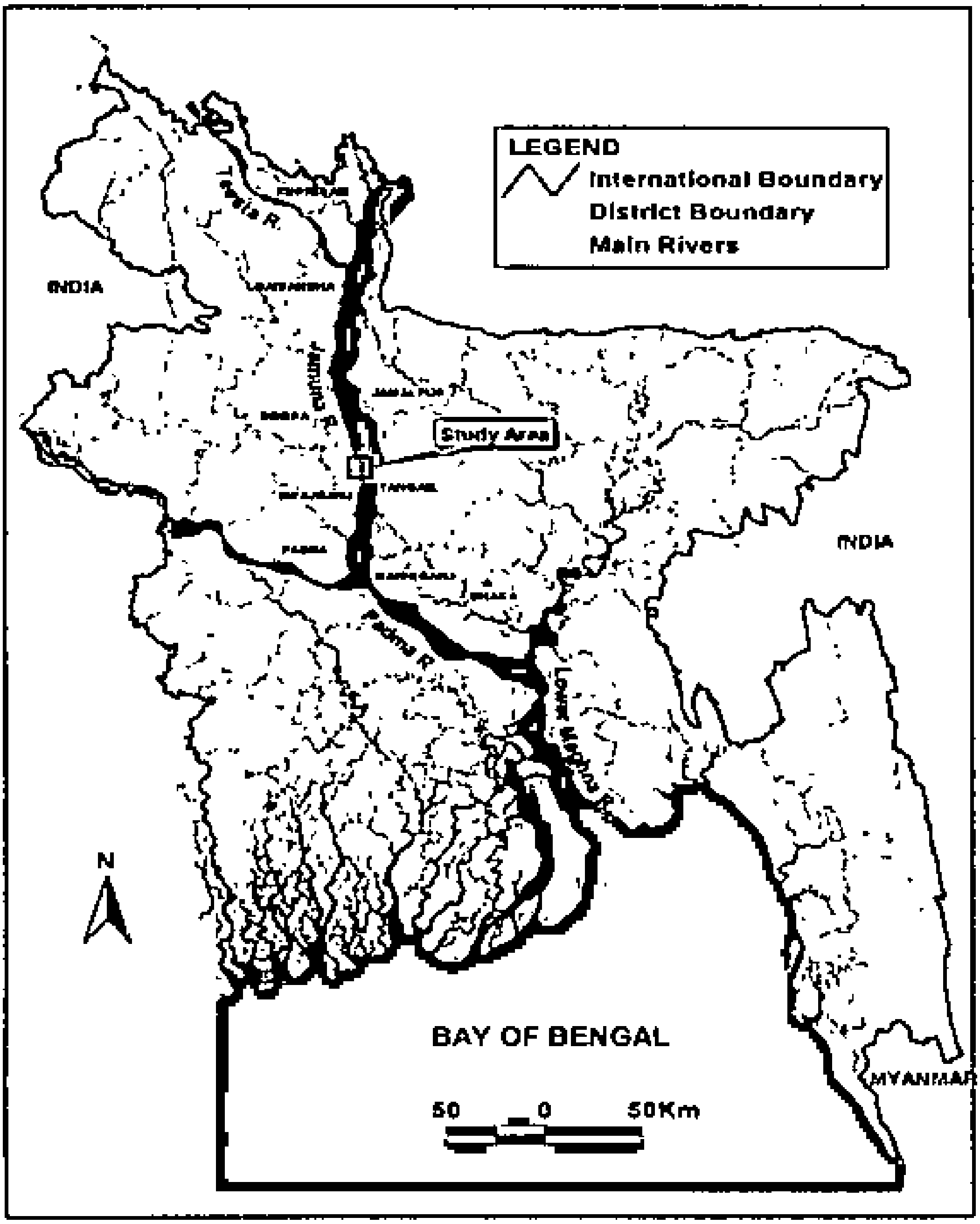


Figure 1.1: River systems of Bangladesh. (Source: BWDB, 2010)

1.2 Objectives with specific aims and possible outcome

This study is intended to assess the morphological stability of the 20 km dredged channel along the braided Jamuna River. The main objective of the study is to assess the erosion processes and its management plan with respect to flow regime. The specific objectives are as follows:

(i) To assess the historical trend of channel shifting based on secondary data.

(ii) To assess the physical response within the dredged channel under changing flow regime.

(iii) To clarify the causes of changes of hydraulic parameters and the sustainability of the dredged channel.

1.3 Rationale of the study

This study would be useful to assess the role of capital dredging in comprehensive river management plan along the braided Jamuna river of Bangladesh. In particular cases:

- It may also serve as a guideline for further studies relevant to this topics;
- It can be helpful for decision making regarding this problems;
- This study finds out some measures that can be used for the fixation of future planning;
- It would provide guideline to undertake similar type of work in other rivers of Bangladesh;

1.4 Scope of work of this study

This study would be helpful to investigate the rate of siltation and stability of an artificial dredged channel along the sand bed braided Jamuna River. The scopes of works of this study are as follows:

- Primary and secondary data collection of the Jamuna River from available sources;
- Satellite image analysis to assess the historical change of channel shifting;
- Assessment of backfilling rate of the dredging;
- Preparation of future dredging plan for braided river using morphological model at the end of the pilot dredging;

1.5 Limitations of the study

Major limitations of this study are summarized below:

(i) The hydro-morphological characteristics of a natural river depends on a number of variables such as water level, flow velocity or discharge, channel planform, bed topography, bankline shifting, bar dynamics, sediment transport etc It was not possible to collect all primary data for this study;

(ii) To clarify the causes of changes of hydraulic flow regime, measurement of all parameters for this study is difficult and quite impossible. The findings are case specific and extrapolation of the result to other areas should be extended with careful judgment,

1.6 Structures of the thesis

Chapter two mainly focuses on the literature review; chapter three prevails study area, while chapter four elaborates methodology of the study. Chapter's five summarizes results and prevails discussion. Finally, in chapter six focuses on conclusion and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Brahmaputra-Jamuna River system

Bangladesh is the lower riparian of Brahmaputra-Jamuna River system. The river is originated in the glacier of Jimayanzhong at the north foot of the Himalayas Mountain in south Tibet of China. Then the river sharply turns southward thus forming the famous yalutsangpojiang great bend. When the river passing through Bacuca enters to India, it is called the Brahmaputra River. The river basin of Brahmaputra-Jamuna includes parts of China, Bhutan, India and Bangladesh. Total catchment area is 560,000 sq.km out of which 42,000 sq.km is lying in Bangladesh. The tributaries of the river are Dudhkuma, Dharla, Teesta, Karotoa and Atrai. The distributaries are Old Brahmaputra, Jhenai, Bangshi and Dhaleswari. The river basin represents a higher rainfall area with an annual average rainfall of around 1900 mm; the water yield per square kilometer of the drainage basin is around 0.03 m^3/s. The major river then rolls down the Assam valley from east to west for a distance of about 720 km and thereafter the river swings round the spurs of the Garo hills and enters Bangladesh. At the Indo-Bangladesh boarder, the river again turns south and continues as Jamuna to its confluence with the Ganges near Aricha. After meeting Ganges River and Meghna River near Chandpur, the combined flow of the three rivers further southwards under the name of river lower Meghna and consequently empty into Bay of Bengal. The river is approximately 2,900 km long, out of which 240 km from Noonkhawa to Aricha is lying in Bangladesh. In response to the rainfall distribution, the river stage varies by about 6m.

The characteristic feature of the hydrograph of the Jamuna is the existence of the broad peak between July-September. The river drains an estimated 620x109 m^3 of water annually to the Bay of Bengal. The discharge varies from minimum of 8,000 m^3/s to maximum of about 100,000 m^3/s while the dominant discharge of the river is 38,000 m^3/s and bank full discharge is 48,000 m^3/s. It has an average surface water slope of around 7 cm/km. The valley slope in Bangladesh decreases gradually from 0.10 m/km to 0.06 m/km. During monsoon, the average width of Jamuna River is 12.5 km with average velocity 2 m/s. The average depth of the main channel of Jamuna is about 8 m and average water depth above the chars is 1m to 2m during flood. Consequently, the Jamuna River carries a heavy sediment load, estimated to be over 500 million tons annually. Most of this is in the silt size class (suspended load) but around 15 to 25 percent is sand (bed load). This sand is deposited along the course of the river and the clay fraction is transported to the delta region. The composition of the bank materials is remarkably uniform and consists of fine sand (FAP 1, 1994). The sand size sediment is relatively uniformly graded. The range of d_{50} values of the Jamuna varies between 0.21mm to 0.14mm. The angle of internal friction is approximately 30° for the Jamuna River. The river is connected with the Padma River near Aricha and the combined flow rolls to Bay of Bengal through Chandpur.

2.2 Geomorphological classifications of river

Rivers are found in different forms and geometries. Geomorphological classifications of channel type have established qualitative links between channel process, form and stability. Leopold and Wolman (1957) classified rivers as straight, meandering and braided. They separated meandering and braided rivers depending on bankfull discharge and slope of the channel. From the laboratory study, (Schumm and Khan, 1972) represent straight, meandering and braided in terms of sinuosity versus valley slope.

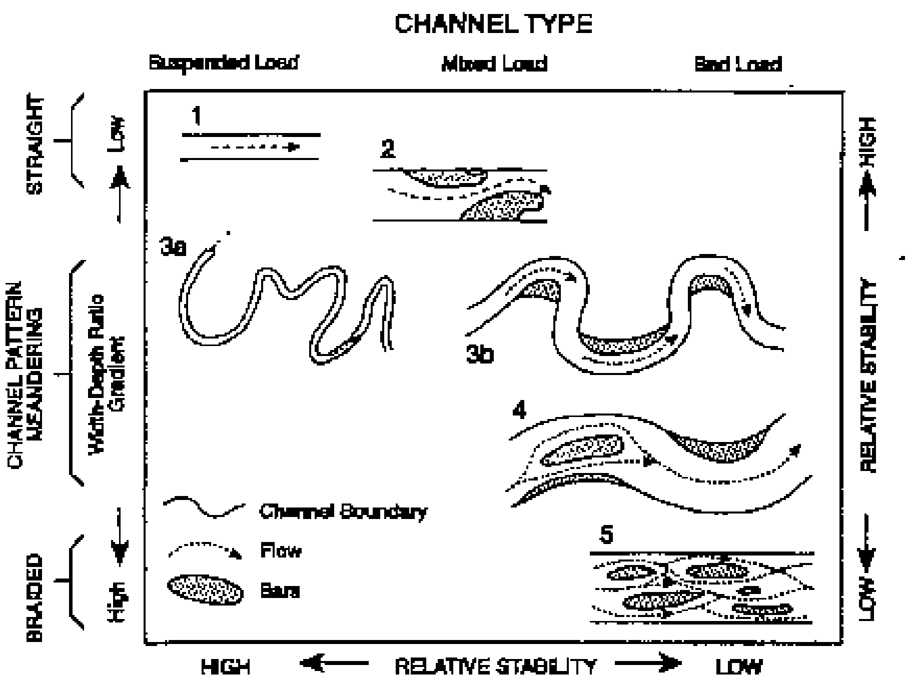


Figure 2.1: Channel classification based on sediment load and system stability. (Source: Schumm, 1977)

Types 1 and 2 are the straight and slightly sinuous channel, resulting from fine sediment transport in suspension having highly erosion-resistant boundary material. Such channels are confined by their bank boundary and display very slow rates of lateral bank shifting and channel evolution. This planform is very rare in the natural rivers. Types 3 and 4 are the meandering planform. Mixed-load stream with relatively mobile bed material and greater sediment supply, resistant but somewhat erodible bank, generally follows meandering courses. These channels migrate freely across the flood plain through bank erosion and point bar growth. Type 5 is a braided planform. Rivers with sufficiently high energy to transport relatively coarse sediment as significant bed load and with weak bank material tend to have multithreaded and braided pattern. Braided channels are very unstable; they wander across their flood plains unpredictably through a combination of rapid localized bank erosion and frequent anabranch avulsion.

2.3 Characteristics of a braided river

The detailed formation processes of a braided river are still poorly understood and the hydraulic parameters of a braided stream are extremely complex (Coleman, 1969). Leopold and Wolman (1964) described the development process of a braided bar in a laboratory flume as shown in Figure 2.2. The uncommented sandy flume channel was straight initially. A small deposit of grains in Figure 2.1 "A" of coarser sediment was introduced by lag deposit of the coarser fraction, which could not be carried by the flow. The probable reason for this initial deposition given by Leopold and Wolman was that the turbulent flow creates the fluctuation of instantaneous velocity, which causes a brief decrease in intensity allowing some particles to rest. Once initiation of the bar has occurred it accretes vertically (shown in "B" and "C") as well as in downstream direction. The presence of a bar reduces the flow area and diverts the flow towards the bank (shown in "D"), initiating bank erosion thus increasing the flow area.

The velocity distribution over a mid-channel growing bar reduces after accreting the bar to a certain level shown in "E" (Ashworth, 1995). This forces the flow further towards the bank attributing the further widening of the channel. Widening of the channel increases the flow area and drops the water level, which results in the bar emerging ("F") for constant discharge. These are the mechanisms of the mid-channel bar initiation as based on (Leopold and Wolman, 1957). Migration of channels within the braid belt is mainly related to the erosion of their outer bends which results from the curvilinear flow or from the lateral or downstream expansion of sand bars, pushing the channels outward (EGIS, 2001).

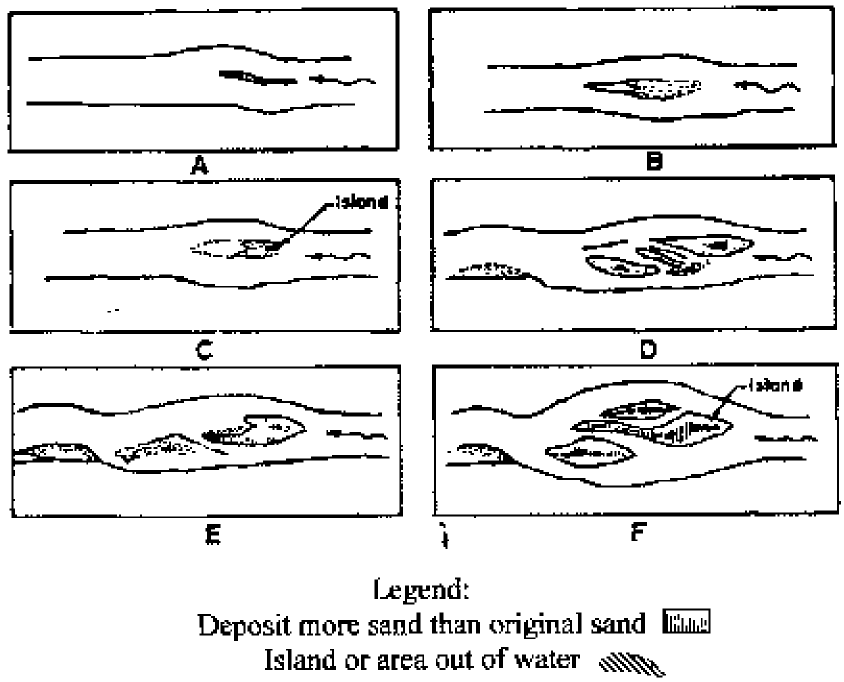


Figure 2.2: Steps in the development of a braiding process (Leopold and Wolman, 1957).

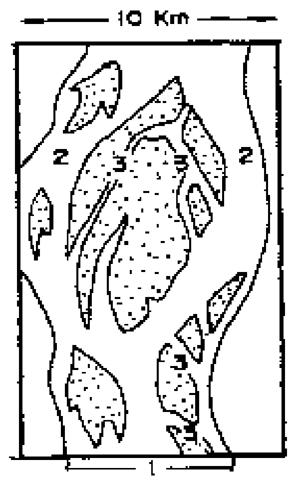


Figure 2.3: Channel classification in the Jamuna River (Bristow, 1987).

In a braided river third orders of channels are present (Williams and Rust, 1969). The order of channels depends upon total discharge and fluctuation of discharge. The first order comprises the whole river. Second order is the dominant channels within the river whilst third order channels are primarily low stage features which modify the bars deposited by the second order channels shown in Figure 2.3. According to Leopold and Wolman (1964), there is a close relation between braiding and meandering. Braided channels may exhibit curves that have a characteristic relation of radius to channel width and the river has at least some reaches that would be called meandering. Also it is found from the study on a large scale sand bed braided river that the flow structure in a bend of an anabranch channel (i.e. second order channel) of a braided river is similar to a meander bend of single thread rivers (FAP 24, 1996).

2.4 Channel formation and shifting process

In a braided river, there exist a number of channels within the braided belt. Leopold and Wolman (1960) derived empirical relations for meandering rivers, which are as follows:

$$\lambda = 10.9B^{1.01} \quad (2.1)$$

$$A = 2.7B^{1.1} \quad (2.2)$$

$$\lambda = 4.7R^{0.98} \quad (2.3)$$

In which λ = meander length, A = amplitude and R = radius of curvature. The definition diagram of these parameters is shown in Figure 2.5.

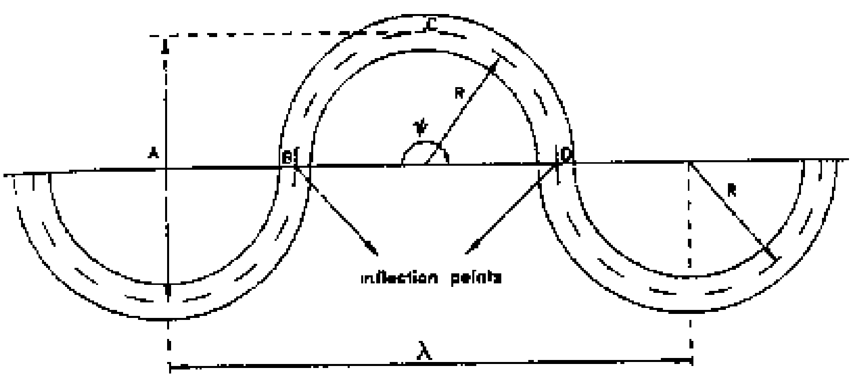


Figure 2.4: Diagram of meandering wave length, amplitude and radius of curvature.

Relating the second order braided channel with the meander formation Klaassen and Vermeer (1988) found some deviations. They derived a relation at a station of the Jamuna River based on Lacey's regime relation, considering different levels in the cross-sections for different discharges and corresponding water surface width and average depth which they estimated from the BWDB measured cross-section. The discharge in an individual channel was estimated as indicated in the regime relations. On average, the flow depth and width relations with discharge are expressed as below:

$$h = 0.56Q^{0.23} \quad (2.4)$$

$$B = 18.9Q^{0.51} \quad (2.5)$$

These relations indicate that the channels of the Jamuna River are quickly responding to adjust their depth and width with the variation of discharges. However, no channel in the Jamuna River is in regime condition and continuous change of channel development and abandonment is a common phenomenon. Due to the periodic formation and decay of large chars and sandbars in the Brahmaputra-Jamuna River, constantly changing river currents attack its banks and cause erosion at apparently random locations. Such bank erosion may initially reach rates of several hundred meters per year and create and embayment in the bank several kilometers long as the river channel seeks to readjust its channel capacity to accommodate a growing char. Historical developments of rivers of Bangladesh are shown in Figure 2.4.

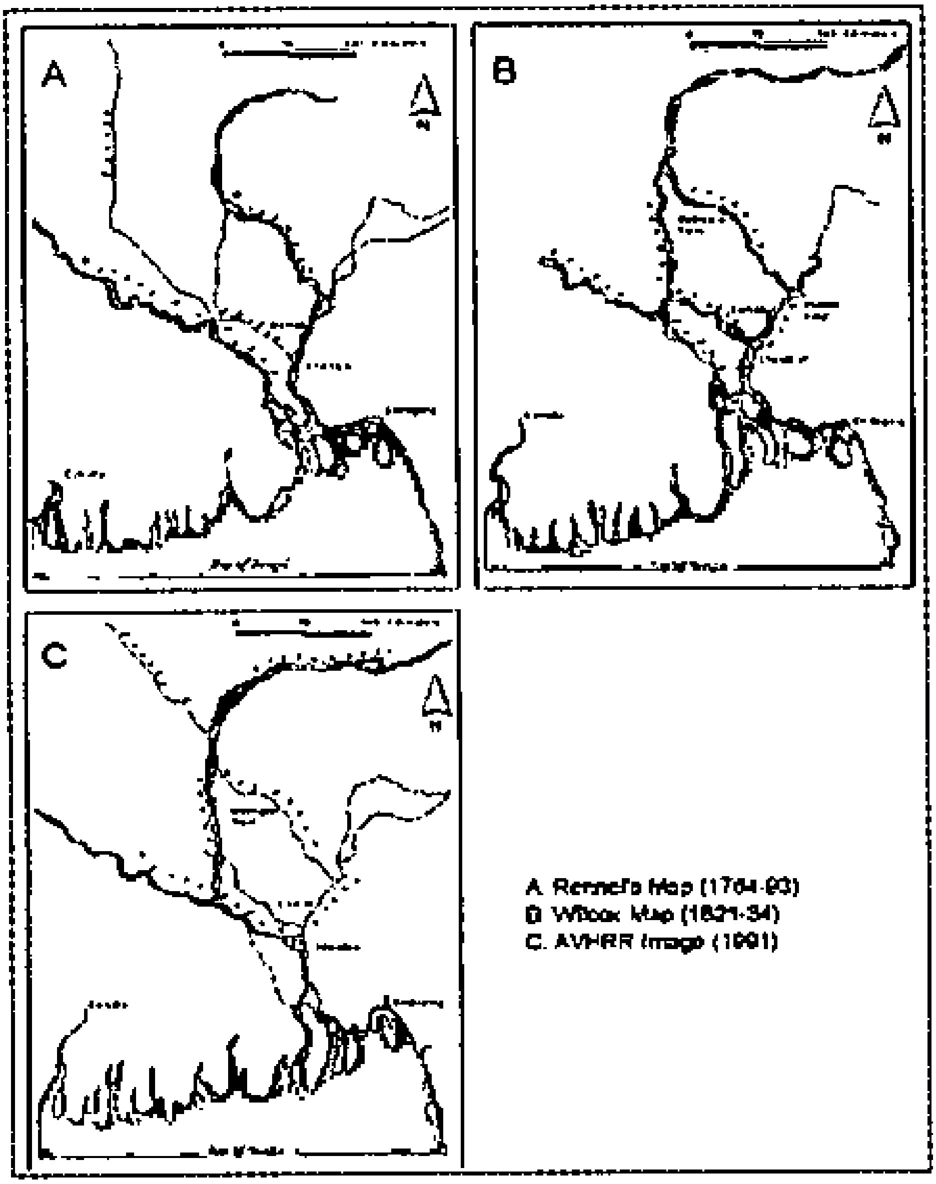


Figure 2.5: Historical development of rivers in Bangladesh.

2.5 Effects on channel stabilization

Channelization involves changing one or more of the interdependent hydraulic variables of slope, width, depth, roughness or size of the sediment load. Channelization has a great impact on a river because it disrupts the existing physical equilibrium of the watercourse. To compensate for the alteration in one or more of the hydraulic variables and to establish a new, stable equilibrium, other parameters will change. The gradient and the velocity of flow determine the erosion and transport of material. The gradient and velocity of flow are increased by channelization and as a consequence the equilibrium is brought out of balance. The watercourse will attempt to regain its state of equilibrium as a result, the increased waterpower can cause bank erosion and the channel may suffer serious scour and ultimately failure, which is if no protective revetment is installed. River channelization often leads to a significant legacy in terms of maintenance and bank/channel stabilization.

The cumulative effects of long-term watershed development and river works have had extensive adverse impacts on our rivers. Direct disturbance to channels by straightening, lining, draining, raising, lowering, clearing, dredging in the name of flood control, navigation and other single-purpose objectives have taken a serious toll on the physical and biological functions of our rivers. The flow field and bed morphology around the bank protection structures either intrusive or nonintrusive, very specially and temporally but maintain certain common features depending on the type of the structures. The strong vortex system in front of and return currents behind the upstream termination of the Sirajganj Hardpoint are the major engines for the morphological variations and are also the main causes of structural failure. Moreover, the intensity of flow around the termination is closely related to the evolution is nearby sandbars (Rahman, 2011).

The applicability of (Ikeda, 1981; Hasegawa, 1984) formulae for bend development is tested to the meandering channels existing in the Jamuna Bridge site. It is found that these formulae are applicable for the braided rivers. Another criterion of (Jaeggi, 1984) is applied to test whether the sand bar in the study reach had obtained its equilibrium height or not. The main channel of the Jamuna River has been shifting from west (right bank) to east (left bank) direction. From 1985 to 1992 at 4 km upstream of the bridge, the shifting of the left bank of the main channel was 1.43 km and in 1996-97 it was 0.65 km described by (Alam, 2004). However during the period from 1997 to 1999, at 4 km upstream of the bridge, the shifting of the left bank of the main channel was 5.04 km.

Channelization has immediate and direct effects on stream processes because it involves direct modification of the river channel. Reasons for modifying river channels include flood control, speedier storm water conveyance and drainage of adjacent lands, navigation, bank stabilization, erosion control and protection of highways (Keller 1976). Most of the early studies on the effects of channelization concentrated on the physical effects and changes that occurred to the stream channel. Later, biological effects also began to be noted and evaluated. In 1978, a Task Committee of the Hydraulics Division of the American Society of Civil Engineers did a general overview on the environmental effects of various hydraulic structures (Task Committee, 1978). The combined effect of the physical and biological changes are benthic macro-invertebrates, fish and aquatic/riparian vegetation from algae and macro-phytes to riparian shrubs and trees, as well as terrestrial animals such as amphibians, reptiles, birds and mammals.

2.6 Erosion problem in the Jamuna River

River bank erosion is one of the major natural disasters of Bangladesh. It has caused untold miseries to thousands of people every year living along the banks of rivers in Bangladesh. To date, erosion alone has rendered millions homeless and has become a major social hazard. Most of the slum dwellers in large urban and metropolitan towns and cities are victims or riverbank erosion. In 2008 the Jamuna, the Ganges and the Padma rivers eroded about 3,230 ha of land, 425 ha of settlement, 290 m of embankment, 1,840m of district road, 590m of upazila road and 3,635m of rural road, during the same period the Jamuna and the Padma eroded 19 educational institutions, 7 hat/bazaars and 2 government offices (CEGIS, 2010). On the other hand, a prediction study by CEGIS based on satellite image for the year 2009 indicates that around 2,180 ha of land, 420ha of settlement, 535m of active embankment, 605m of district road, 900m of Upazila road and 4,320m of rural road are vulnerable to erosion along the Jamuna, the Ganges and Padma. Moreover, 23 educational institutions, 4 hat/bazaars, 2 government offices and 2 health centers are vulnerable to erosion along the Jamuna and the Padma rivers. Satellite image analysis reveals that Brahmaputra-Jamuna river is migrating towards west/right bank floodplain. From literature review, analysis of historic maps and satellite images indicates that the

Brahmaputra-Jamuna centerline has moved and average of 4.30 km west since 1830, with a maximum westward movement of 13 km at its northern end. Analysis of a series of recent images shows that this river is migrating westward at an average rate 75 m per year (CEGIS, 2010). The centerline of Brahmaputra-Jamuna is moving and also has been widening. The effects of bankline erosion and widening of the river channel have been great.

Sirajganj is an old established town in Bangladesh. The urban and peri-urban development has been expanded close to the river bank. It is reported that one kilometer of right bank has already shifted in the westward direction since 1830 (Halcrow, 1994). The increased river flow is attacking the bank directly at Kalia-Haripur bend. Local people informed that some of them had to shift their homesteads from the bank four to six times and many of them lost their agricultural lands into the river. At Char Malshapara, a school and a madrasa went into the river. Char Malshapara mosque shifted three times. Potential erosion at downstream of Hardpoint brought the bank line near BRE. The people of these areas have become landless as well as poor. According to the information of the Union Parishad member and the common people of Char Malshapara and Mara Gram, 40% of the total people being landless and shifted from the villages. Bank erosion has made their life miserable.

The unique natural setting of Bangladesh in the South Asian Sub-Continent and the characteristics of tropical monsoon are greatly responsible for flood, sedimentation, riverbank erosion and population displacement in Bangladesh. River bank erosion is closely related to the magnitude of flood and bank materials of alluvial character. Rivers flowing through these loose alluvial soils carry most of the eroded materials as sediment on their way to the Bay of Bengal (Elahi, 1991; Islam, 1985). It is a frequent natural disaster in Bangladesh. CEGIS annually estimate the amount of erosion and accretion along the three main rivers: (the Jamuna, the Ganges and the Padma) of Bangladesh (CEGIS, 2010). From the study it was found that Jamuna River is widening and both banks are migrating outwards at a high rate for the last few decades. During the last three and half decades (1973 to 2010), the net erosion along the 220 km long Jamuna River was about 71,068 ha. The highest erosion was in Sirajganj district (20,967 ha). The annual erosion along the Jamuna varies from one year to the other and also from one reach to the other reach (CEGIS, 2010).

2.7 Erosion management and river training works

The rate of erosion along the right bank of the Jamuna River is higher than the left bank. The Brahmaputra Right Embankment (BRE) was built during the late 1950s and mid-1960s to protect the flood plain against flooding. The component was formulated to study on short term and long term protection along the right bank of the Jamuna River (FAP1, 1994). Out of 10 locations, 6 priority vulnerable locations were selected for bank protection measures. Under this component, construction of Hardpoint was suggested to stabilize the boundaries of the braided belt. During 1998, hard points were built at Sirajgang, Sariakandi and Mathurapara. The construction costs of the Hardpoint were very high. About 30 river training structures were constructed along BRE mostly during the last decade.

Bangladesh Water Development Board (BWDB) has mixed experiences of both failures and successes of such projects for the protection of BRE (Uddin, 2007). During the period of 1999-2002, fifteen RCC spurs have been constructed at different locations of BRE with variable length and spacing. Out of these, five were damaged (Uddin, 2007). The primary causes of failures of different bank protection structures are flow slide, oblique flow towards bankline or structure and generated excessive local scour around bank protection structures (BWDB, 2008; BWDB, 2006; BWDB, 1999). Repair and maintenance works are very important for the river training works even around very expensive structures such as the Hardpoint (BWDB, 1999).

Figure 2.6: Modes of failure of Sirajganj Hardpoint at 2009.

2.8 Environmental and social impacts of dredging

Dredging of the river is likely to have both positive and negative impacts on the environmental and social components. Positive Impacts of river dredging would include increase in carrying capacity of the rivers leading to reduce the erosion. In addition to increased navigation facilities, access to availability of surface water for domestic and industrial use will improve. Definite improvements in flooding and drainage can be expected owing to increased conveyance capacity of the rivers. Increased availability of surface water would lead to increase in irrigated area which in turn will have very positive impact on agricultural crop production. Dredging would make the rivers more stable thereby reducing river erosion which is one of the major causes of increasing landlessness. Reduced river erosion would ultimately contribute to poverty alleviation.

Most negative impacts of dredging are associated with the way the dredged spoil is disposed. Common environmental and social components are likely to be negatively impacted by dredging may include disturbance created for aquatic flora and fauna in the water body, contamination of water due to leakage of oil and lubricants from the dredger, land degradation due to disposal of the dredged material, contamination at the dredged spoil disposal site, displacement of communities from the dredged spoil disposal site, etc. However, it is possible to minimize the effect of the negative impacts through mitigation measures developed as a part of the environmental and social impact assessment (EIA/SIA) studies. In fact, proper operation and maintenance of dredgers would check spillage of oil and lubricants thereby averting contamination of water while properly planned and implemented disposal of dredged materials will take care of most negative impacts.

2.9 Hydrometric information from Pilot Capital Dredging

The hydrometric data (cross section, water level, discharge, sediment concentration etc) within study area would be collected from Institute of Water Modelling and Bangladesh Water Development Board. Analysis of collected hydraulic data would be made to find out the variation in the depth of flow resulting from sedimentation or scouring.

2.9.1 Sediment concentration and properties of river bed sample

Properties of a single sediment particle that is important in the study of sediment transport. The sediment properties are size, shape, density, specific gravity, specific weight and fall velocity. Size is the basic and most readily measurable property of sediment. Shape also affects the transport of sediment, but there is no direct quantitative way to measure shape and its effects. The shape factor is 1.0 for a sphere. Most natural sand particle have SF = 0.70.

The suspended sediment samples were collected from Jamuna River at Sirajganj Hard Point to Dhaleswari offtake during 2011-2012. The sediment concentration measurement corresponding to the relative depths was done as mentioned before. Sediment sample had been collected at 2 verticals (maximum and minimum depth) during discharge measurement. The location and time of sampling was related with the discharge measurement timing and location. The following observations are given below:

- The average sediment concentration in the Jamuna River within the study area was found 419.80. mg/l, 446.83 mg/l, 444.15 mg/l, 376.52 mg/l, 409.41 mg/l in June, July, August, September and October 2011 respectively.

- The average sediment concentration in the Jamuna River from Sirajganj Hard Point to Dhaleswari Offtake was found 402.56mg/l and 417.53mg/l in May & June 2012 respectively. The summary of sediment concentration is given in Table 2.1.

Table 2.1: Sediment concentration in the Jamuna River at different locations

Date	Location	Average sediment concentration (mg/l)
22/05/2012	Sirajganj Hard Point	453.29
	Dredged Channel	425.07
	Right channel at D/S of Bangabandhu Bridge	278.57
	Left channel at D/S of Bangabandhu Bridge	453.34
05/06/2012	Sirajganj Hard Point	252.56
	Dredged Channel	161.08
	Right channel at D/S of Bangabandhu Bridge	208.75
	Left channel at D/S of Bangabandhu Bridge	216.24
16/06/2012	Sirajganj Hard Point	352.79
	Dredged Channel	350.85

Date	Location	Average sediment concentration (mg/l)
	Right channel at D/S of Bangabandhu Bridge	432.11
	Left channel at D/S of Bangabandhu Bridge	469.84
20/06/2012	Sirajganj Hard Point	418.48
	Dredged Channel	460.82
	Right channel at D/S of Bangabandhu Bridge	533.78
	Left channel at D/S of Bangabandhu Bridge	486.51
26/06/2012	Sirajganj Hard Point	353.60
27/06/2012	Left Channel adjacent to dredged channel	523.12
	Right channel at D/S of Bangabandhu Bridge	574.24
	Left channel at D/S of Bangabandhu Bridge	885.71
26/06/2011	Right channel at D/S of Bangabandhu Bridge	271.63
	Left channel at D/S of Bangabandhu Bridge	419.10
03/07/2011	Sirajganj Hard Point	489.89
	Right channel at D/S of Bangabandhu Bridge	546.51
	Left channel at D/S of Bangabandhu Bridge	516.64
09/07/2011	Sirajganj Hard Point	350.85
	Right channel at D/S of Bangabandhu Bridge	572.26
	Left channel at D/S of Bangabandhu Bridge	539.17
12/08/2011	Right channel at D/S of Bangabandhu Bridge	574.24
	Left channel at D/S of Bangabandhu Bridge	243.89
22/08/2011	Right channel at D/S of Bangabandhu Bridge	581.81
	Left channel at D/S of Bangabandhu Bridge	364.99
10/09/2011	Right channel at D/S of Bangabandhu Bridge	426.34
	Left channel at D/S of Bangabandhu Bridge	326.71
02/10/2011	Right channel at D/S of Bangabandhu Bridge	250.53
	Left channel at D/S of Bangabandhu Bridge	370.67

2.9.2 Siltation of the dredge channel

Sediment load is predominant for development of river bed and bank formation as well as accretion of Jamuna River. The river regime is frequently reshaping its section due to sand bar movement and it accelerates with the magnitude of flood. It is seen that the dredged area is gradually silted up but increasing the conveyance area by eroding the char both side of the dredged channel. The backfill measurement was carried out during dredging period on the dredged channel and the backfill rate was found around 35-40 percent. The observed siltations in the dredged area in different dates are listed in Table 2.2.

Table 2.2: The observed siltation in the dredged area in different dates

Chainage	Actual Dredge Volume (lakh cum)	Observed Siltation in dredged area			Remarks
		Date	Backfil volume (lakh cum)	% of dredge volume	
Km 0.0- km 3.0	19.90	13.09.13	12.33	62	1st year maintenance dredging-2013
Km 10.0- km 12.50	55.09	14.09.13	41.11	75	
Km 13.50- km14.00	5.63	14.09.13	5.62	99.87	
Km 0.0- km 3.0	19.90	30.07.13	12.06	61	
Km 10.0- km 12.50	55.09	31.07.13	45.32	82	
Km 13.50- km14.00	5.63	31.07.13	5.33	95	
Km 0.0- km 3.0	19.90	24.06.13	12.32	62	
Km 10.0- km 12.50	55.09	25.06.13	21.26	39	
Km 13.50- km14.00	5.63	25.06.13	4.12	73	
Km 0.00 - km 14.00	118.86	07.06.12	43.47	37	Capital pilot dredging, 2012
		16.06.12	50.17	42	
		26.06.12	45.97	39	
Km 0.45- Km 14.00	99.96	08.07.12	49.96	50	
Km 0.55- Km 14.00	93.12	16.07.12	53.44	57	
Km 0.45-Km 14.00	99.96	23.07.12	50.88	51	
		03.08.12	49.79	50	
		24.08.12	46.28	46	
		12.09.12	49.48	49	
		9.10.12	57.29	57	
		22.10.12	59.31	60	
Km 16.0- km 22.0	48.73	08.06.12	7.20	15	
		15.06.12	6.21	13	
		27.06.12	13.76	28	
		11.07.12	13.91	29	
		18.07.12	17.70	36	
		25.07.12	17.78	36	
		03.08.12	20.29	42	
		25.08.12	22.29	46	
		12.09.12	12.64	26	
		10.10.12	16.02	33	
		23.10.12	17.15	35	

2.10 Summary on literature review

Human manipulation that changes the shape of a river's natural flow patterns can affect the river morphology. The literature review discussed the river pattern, classified on the basis of appearance in a plan view as braided, straight and meandering river. These review also emphasis mainly on the characteristics of the Jamuna River, flow process at bends and bar migration through bends with limited emphasis on bank erosion and associated impacts in Bangladesh. Development and abandonment of channels within a year is a very common phenomenon in the river, which makes the river difficult for navigation. Widening of the river also aggravated the problems. The potential impacts of sedimentation in the Jamuna Rivers of Bangladesh are causing more floods, bank erosion, char formation, channel shifting etc. All of which have severe implications on agriculture production and livelihood of people. A pilot capital dredging is formulated to reduce the erosion and maintain the navigability of the river. It is important to formulate a project where dredging limits satisfy the requirements, dredging footprint and potential environmental impacts. But before launching of any dredging work, it is important to conducting of hydrographic survey, preparation of route plan; dredging methodology and the disposal of the dredged materials are important activities for the sustainability of the dredging channel. Recently, CEGIS observed and predicted that during the last three and half decades (1973 to 2010) the net erosion along the Jamuna River was about 71,068 hectares of which 16,122 hectares in Sirajganj district. CEGIS also identified the most vulnerable location of the reach is Kalia-Haripur area in between two important structures, Sirajganj Hardpoint and right guide bund of Bangabandhu Bridge. So a complete study is necessary for the understanding of overall situation. The present study will be useful for conducting future development action and policy formulation related to bank erosion.

CHAPTER THREE
STUDY AREA

3.1 Study area

The study area is located from upstream of the Sirajganj Hardpoint to downstream of the Bangabandhu Bridge near Dhaleswari offtake as shown in Figure 3.1. The total length of the study area is around 20km, split by two segments. The upper segment is 14 km, starting from upstream of Sirajgonj hard point as KM-0, which end at KM-14. The lower segment is 6 km, starting from KM-16, which end at KM-22. The centerline co-ordinate of the 1st segment KM-0 is (24°31'28", 89°42'43") and KM-14 is (24°24'25", 89°45'35"). The centerline co-ordinate of the 2nd segment KM-16 is (24°23'36", 89°46'10") and KM-22 is (24°20'27", 89°47'3"). The design section has considered for dredging as 120m bed width, 1:3 side slope and 7 cm/km longitudinal slope. The channel upstream bed level at KM-0 was 3.00 mPWD and downstream bed level at KM-14 was -2.40 mPWD but a drop of bed level from 2.42 mPWD to -2.00 mPWD was done at KM-8.25 to KM-8.50. The bed level at KM-16 was 0.00 mPWD and at KM-22 was -0.42 mPWD.

Table 3.1: Centerline coordinates of dredging alignment from Ch-0.0 m to Ch-22,000 m

Sl. No	Chainage (m)	Latitude	Longitude	Sl. No	Chainage (m)	Latitude	Longitude
1	0	24°31'27"N	89°42'43"E	12	11000	24°25'52"N	89°44'50"E
2	1000	24°30'55"N	89°42'48"E	13	12000	24°25'21"N	89°45'00"E
3	2000	24°30'24"N	89°42'57"E	14	13000	24°24'51"N	89°45'14"E
4	3000	24°29'52"N	89°43'03"E	15	14000	24°24'25"N	89°45'03"E
5	4000	24°29'21"N	89°43'14"E	16	16000	24°23'36"N	89°46'09"E
6	5000	24°28'51"N	89°43'28"E	17	17000	24°23'05"N	89°46'20"E
7	6000	24°28'22"N	89°43'44"E	18	18000	24°22'33"N	89°46'29"E
8	7000	24°27'54"N	89°44'03"E	19	19000	24°22'02"N	89°46'38"E
9	8000	24°27'25"N	89°44'17"E	20	20000	24°21'30"N	89°46'46"E
10	9000	24°26'55"N	89°44'30"E	21	21000	24°20'59"N	89°46'54"E
11	10000	24°26'23"N	89°44'41"E	22	22000	24°20'27"N	89°47'02"E

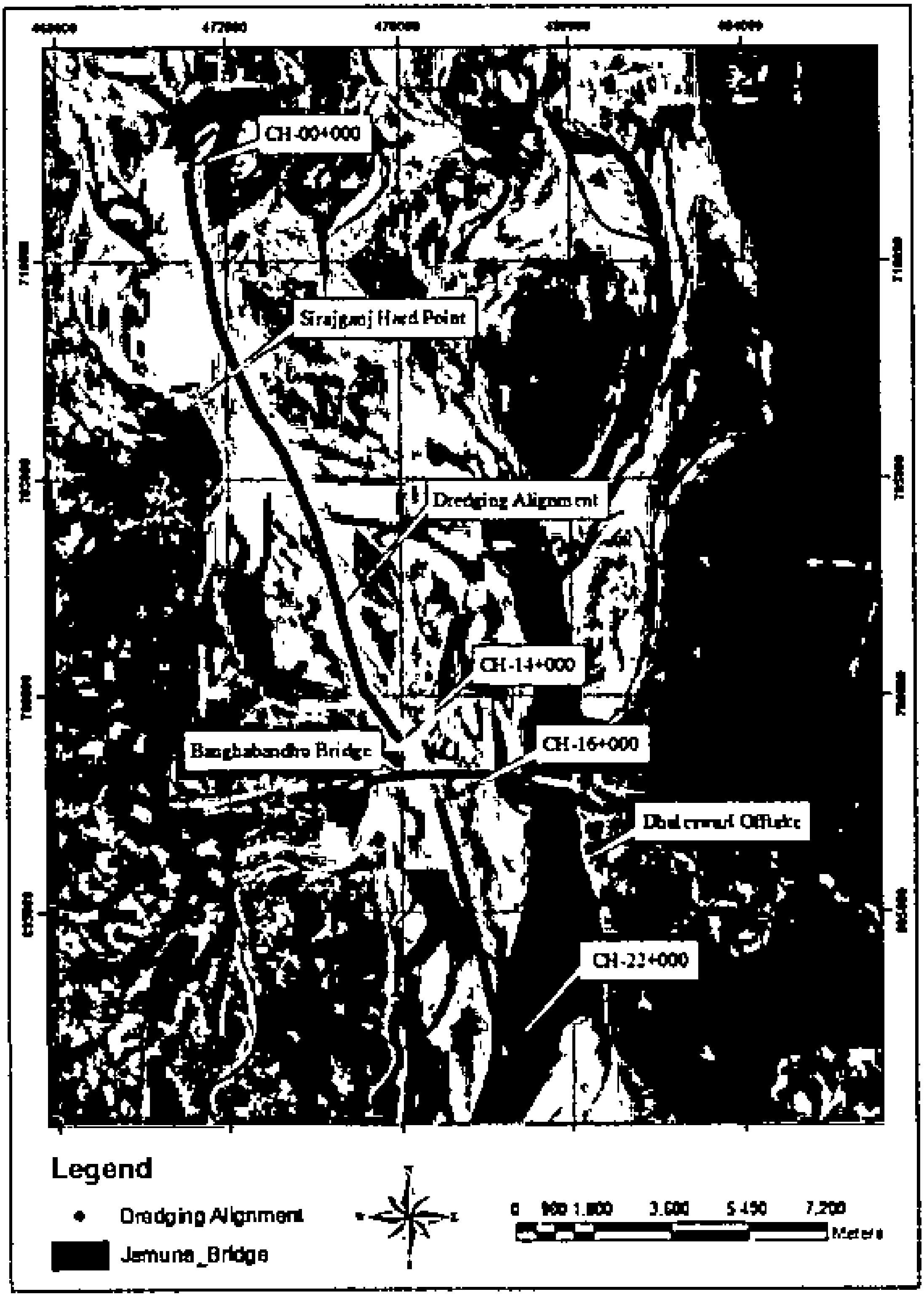


Figure 3.1: The study area showing from Sirajganj Hard Point to Dhaleswari offtake.

3.2 Physical features of the study reach

River bank erosion is a big problem of Bangladesh, especially along the braided Jamuna River. Thousand hectares of land are eroded each year by the mighty Jamuna River. Social and economic problems are created in consequence of erosion.

3.2.1 Topography

The area is a low lying flood plain area. Char Malshapara Gram and Mara Gram villages are located at 400m to 650m inside from Brahmaputra Right Embankment (BRE) respectively. Homesteads are located in a scattered way where lands are relatively high and trees are found to give them privacy and shade. Due to consecutive river bank erosion, people have to shift their houses several times and they take shelter near Brahmaputra Right Embankment (BRE). The crest level of Sirajganj Hardpoint is (+) 16.75 mPWD, whereas approximate ground level is (+) 13.00 mPWD (Uddin, 2010).

3.2.2 Demography

The study area is located in Sirajganj Sadar Upazila. The demographic characteristics of the Upazila are reflected here. Sirajganj Sadar Upazila with an area of 325.77 sq. kilometer has a population of 389160. Among them, the number of male is 51.54%, female 48.46%; Muslim 95.16%, Hindu 4.80% and others 0.04%. Average literacy of the area is 29.8% amongst which male literacy is 35.6% and female is 23.5%. The significant educational institutions are BL High School (1869). Gyandayini High School (1884), Islamia College (1887), and Sirajganj Government University College (1940). Main occupations are agriculture 25.17%, agricultural labourer 15.76%, wage labourer 4.37%, commerce 16.09%, service 12.55%, weaving 4.10%, transport 3.53%, industrial labourer 4.12%, and others 14.31%. Total cultivable land is 23872.93 hectares, fallow land 772.16 hectares, single crop 21.44%, double crop 47.54%, and triple crop land 31.02%; and cultivable land under irrigation is 42.38%. Among the peasants, 7.53% are landless, 10.12% are marginal, 61.99% are small, 17.81% are intermediate and 2.55% are rich.

3.2.3 Hydro-Morphology

The Brahmaputra-Jamuna River originates in Tibet on the northern slope of the Himalayas and drains snowmelt and rainfall from China, Bhutan, India and Bangladesh. Before it meets with the Ganges River at Aricha in Bangladesh, the river travels a length of 2,740 km. Its total catchment area is 570,000 km^2, of which only 7% is within Bangladesh. Annual average precipitation in the catchment is 1,900 mm, of which more than 80% precipitation occurs during the 5 months of the monsoon. The water level starts rising in March/April due to snowmelt in the Himalayas and may attain its peak between the beginning of July and mid-September. The annual average flow is 20,000 m^3/s as measured at Bahadurabad and the maximum estimated discharge is 1,00,000 m^3/s in 1998 (EGIS, 2000). Minimum flow in the river generally occurs at the end of February or the beginning of March. The recorded low flow was 2,860 m^3/s in 1971 (FAP 24, 1996).

In the study reach, BWDB have no permanent discharge measurement station. IWM measures discharge at three selected locations (Sirajganj Hard Point, upstream and downstream of the Jamuna Bridge) at 15 days interval from April to October, 2012. The average water level slope of the Jamuna River is 7.5 cm/km, varying from 8.5 cm/km in the upstream part to 6.5 cm/km at the downstream end of the river (EGIS, 2000). The Jamuna River is a braided river with a braiding index that varies spatially and temporally. The range of variation is 2 to 5 (Klaassen and Vermeer, 1988). The overall width of the river is also varied spatially and temporally, from 6 to 14 km (FAP 24, 1996). Generally, the braiding index and the overall width are larger at the upstream part than farther downstream, probably due to the effects of higher slope and grain sizes (Klaassen and Vermeer, 1988). The overall width of the river shows an increasing trend towards westwards, especially at the upstream part of the river within Bangladesh (Halcrow, 1993).

3.2.4 Sediment Transport

The bed material size of the Jamuna River was decreased from upstream towards downstream and their range varies from 0.22 mm to 0.16 mm. The average annual sediment discharge of the river is 590 million tons, which is consisted of 200 million tons of sand (diameter above 0.06 mm), and the remained are silt and clay. Bank material of the Jamuna River consists of loosely packed silt and fine sand, highly susceptible to erosion. The average concentration of sand fraction varies between 300 mg/l to 500 mg/l (FAP 24, 1996).

3.2.5 Infrastructures

The bend of the study area is a flood plain with cluster homestead, cultivable and fallow land. The study area is surrounded by Sirajganj Hardpoint at North, Bangabandhu right guide bund at South, Brahmaputra Right Embankment (BRE) at West and the Jamuna River at East. There were few schools, mosques, madrasa, bazar which had to shift several times and gradually being lost due to erosion. Inside the study area there is no regulator and drainage channel. To protect Sirajganj town a massive Sirajganj Hardpoint was constructed in 1998 under (FAP 1, 1994). High Flood Level (HFL) and Low Water Level (LWL) are considered (+) 15.75 m, PWD and (+) 6.80 m, PWD respectively and design flow velocity is 3.7 m/s. The crest level is (+) 16.75 mPWD, whereas approximate ground level is (+) 13.00 mPWD. The side slope of the Hardpoint is 1V: 3.5H. The Sirajganj Hard Point faced the high flood in the history of the Jamuna in 1998 just after its construction. The Brahmaputra Right Embankment (BRE) was built during the late 1950s and mid of 1960s to protect the flood plain against flooding.

3.3 Bank erosion of the study reach

River bank erosion is an annual phenomenon in Bangladesh and the country is located in a large floodplain delta complex of three major river system (the Ganges, the Brahmaputra and the Meghna). Due to river bank erosion, the people are displaced and it creates social and economic problem in Bangladesh. The literature review is primarily directed to an overview of the history of erosion and its present status. Bangladesh Water Development Board (MPO, 1986) has estimated that about 1200km of river banks in Bangladesh are under active erosion of which more than 500km face severe erosion problems. The river bank erosion differs from river to river and reach to reach. Bangladesh is a country of more than 120 million people with 90 percent dependent on agriculture (BBS, 2001). In a typical year, one fifth of the total 147,570 km^2 of land in the country is severely flooded; and about 2400 km of bankline annually experience major erosion (Islam, 1985).

The urban and peri-urban development has been expanded close to the river bank, such as Sirajganj town in Bangladesh. It is reported that one kilometer of right bank has already shifted in the westward direction since 1830. The increased river flow is attacking the bank directly at Kalia-Haripur bend. Local people informed that some of them had to shift their homesteads from the bank four to six times and many of them lost their agricultural lands into the river. Potential erosion at downstream of hardpoint brought the bank line near Brahmaputra Right Embankment (BRE). The people of these areas have become landless as well as poor. Bank erosion has made their life miserable.

CHAPTER FOUR

METHODOLOGY

This chapter describes the methodology and planning of different activities of this study such as data collection, analysis and reporting etc. In fact, this chapter is a mirror of this study. The overall methodology of this study is representing through a schematic diagram shown in Figure 4.1:

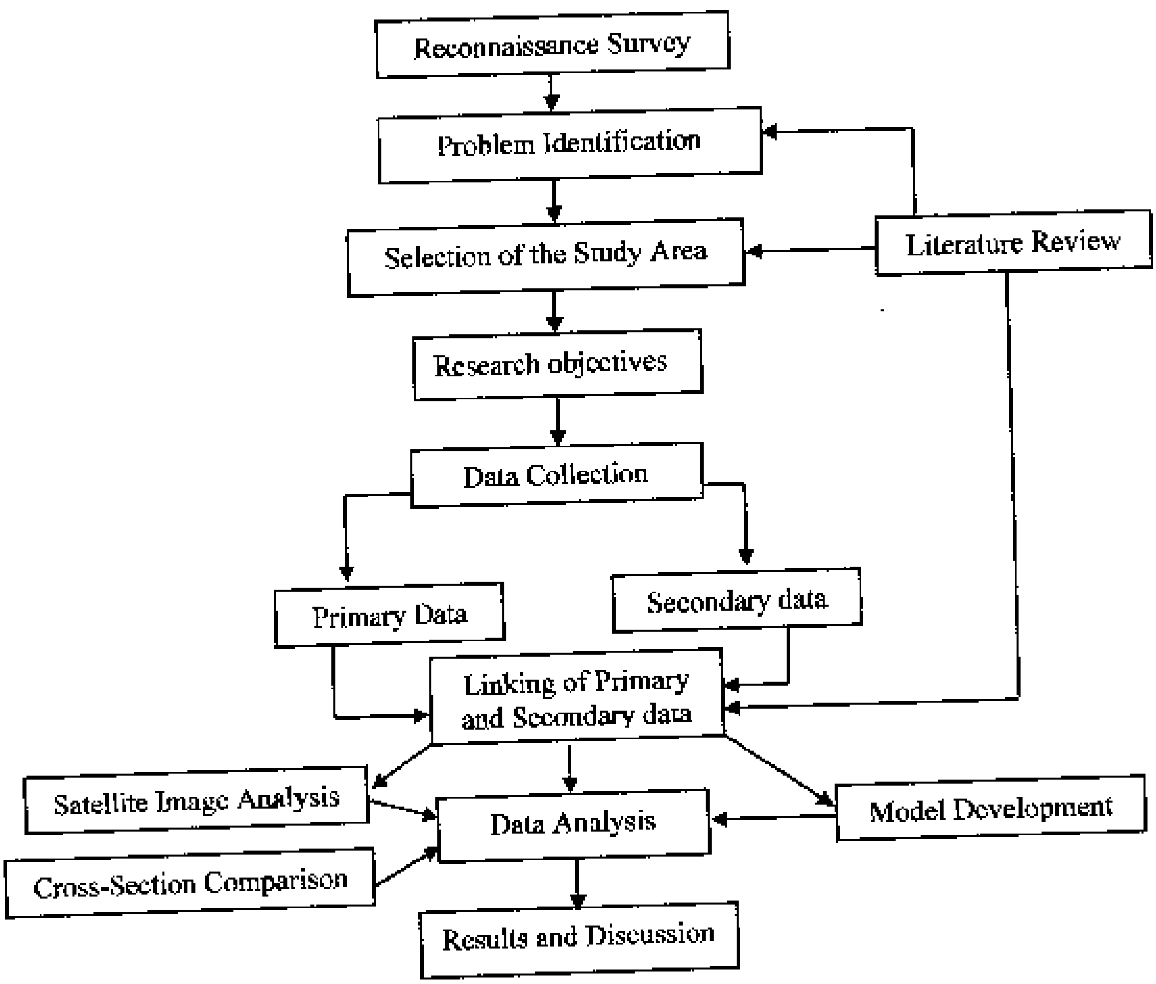


Figure 4.1: Methodological flow chart of the study.

4.1 Reconnaissance Survey

Reconnaissance survey is essential for conducting a research. An understanding is needed to realize the magnitude of river bank erosion and its impacts on river morphology. It is also essential for setting an outline for the overall study. The objective of the reconnaissance survey was to quickly obtain the basic information and developing the overall understanding about the study area. It has been done by-

- Concepts about the study are developed from the previous relevant studies.
- The several articles from newspaper, journals, seminars and also web document influence to conduct the study.
- Knowledgeable people around the study area during reconnaissance survey also helped me to formulate the concept.

4.2 Data Collection

The analysis of this study is based on secondary data. Primary data was also used to clarify the hydraulic parameters under changing flow regime. Following data were used for these studies:

(i) Water level, discharge and sediment data;

(ii) Bathymetric data, velocity profiles and water surface slopes;

(iii) Grain size distribution of the suspended sediment;

(iv) Satellite images, which covering the flood plain and showing important features like point bars, alternate bars, middle bars, palaeo channels etc.;

4.2.1 Primary data collection

Most of the bathymetric and discharge data in this study were collected from pilot capital dredging project and used as a primary data in this study which is formally permitted from Project Director, Bangladesh Water Development Board. The discharge measurement has been conducted using Acoustic Doppler Current Profiler (ADCP). The sediment concentration of Jamuna River has been measured in several places at the time of discharge measurement period. The sediment samples were collected at 0.20, 0.60 and 0.80 depth. The analysis of the samples is done in the IWM laboratory at Dhaka. The water level data were collection from Bangladesh Water Development Board (BWDB) and IWM.

4.2.2 Secondary data collection

Secondary data were collected from IWM, BWDB and CEGIS. The bathymetric survey data for this study were collected from IWM. Historical hydrometric data such as water level, discharge, sediment concentration, bed material, etc. were also collected from IWM and BWDB. Satellite images were used in this study, which images were collected from Center for Environmental and Geographic Information Services (CEGIS). All images acquisition dates were in dry seasons. The lists of image that are used in this study are shown in Table 4.1.

Table 4.1: List of imageries that are used in this study

Year	Image acquisition date	Image type	Resolution
2007	14 January 2007	ASTER	15m×15m
2008	9 December 2007	IRS LISS	24m×24m
2009	13 February 2009	IRS LISS	24m×24m
2010	15 January 2010	IRS LISS	24m×24m
2011	19 January 2011	IRS LISS	24m×24m
2012	27 November 2012	IRS LISS	24m×24m

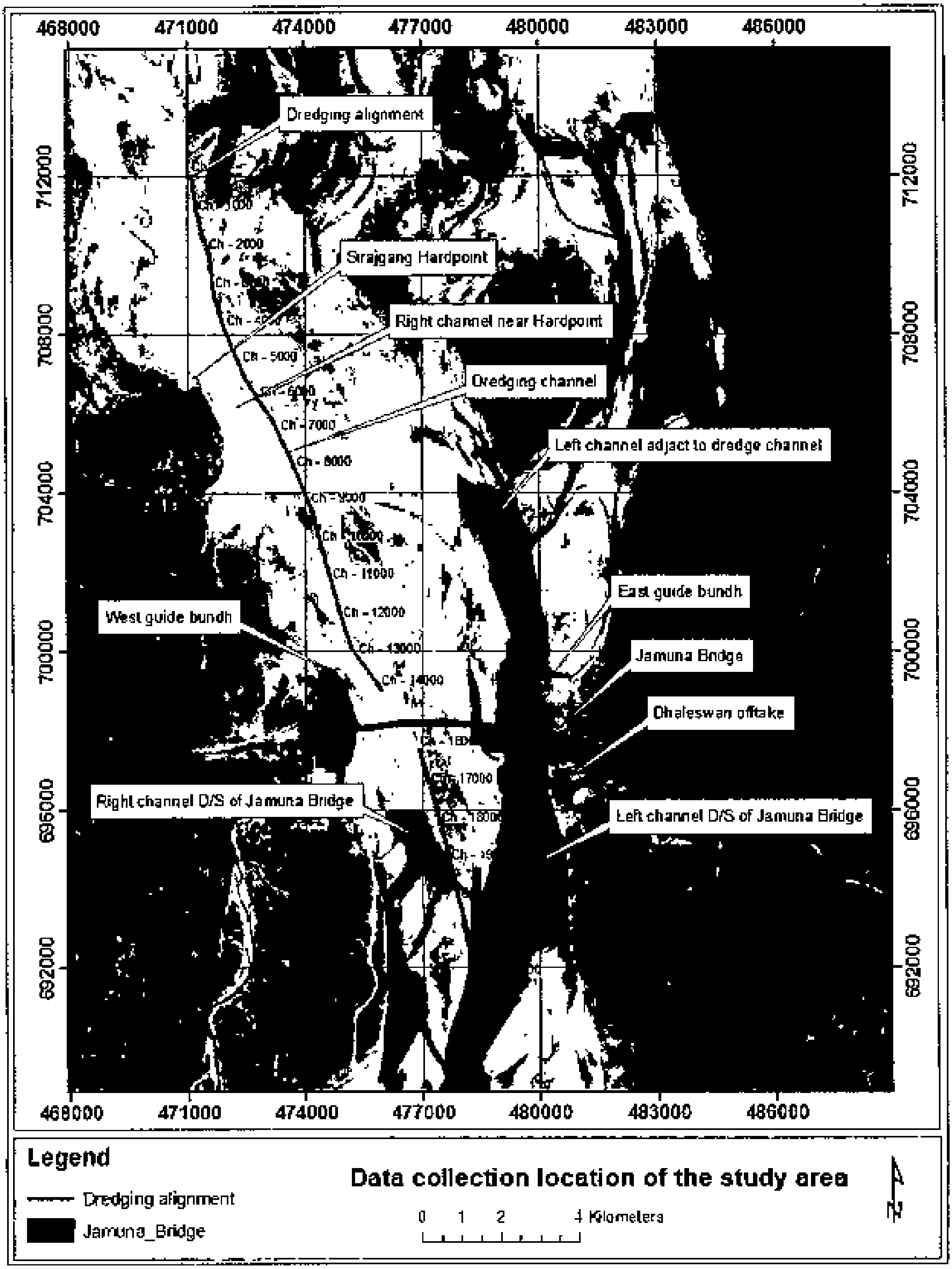


Figure 4.2: Location map around the study area from Sirajganj Hardpoint to Dhaleswari Offtake.

4.3 Data analysis

The sustainability of the dredged channel would be assessed by analyzing the data so far available on bathymetric data, sediment concentration, time-series satellite images, water level and discharges data around two important river training structures (Sirajganj Hardpoint and Right Guide Bundh of the Bangabandhu Bridge) along the Jamuna River.

4.3.1 Satellite image analysis

GIS techniques were used to analyze the satellite images. Time series satellites images were used to understand the flow and erosion processes of a developing bend. The time-series geo-referenced satellite images were superimposed to assess the historical trend of channel shifting of the river courses. Findings of the previous analysis were compared with the result obtained by analyzing the recent available data on flow and sediment transport. Geo-referenced images were used to delineate the large-scale bed-forms such as sandbars movement. The delineated sandbars were superimposed in GIS environment to assess the shifting pattern and to assess their translation process.

4.3.2 Cross-section comparison

The bathymetric data were plotted from 2010 to 2013 at four locations within the study reach. These data were plotted with and without dredging condition under changing flow regime to determine the dynamics of the river, trend of channel shifting, channel planform and river bank erosion processes. In this analysis sediment concentration and discharge also relate with the cross-sections data. The rate of river bank erosion and changing planform of a river course is also related to the rate of sediment concentration and discharges.

4.3.3 Analyses of sediment concentration and depth average velocity

Sediment load is predominant for development of river bed and bank formation as well as accretion of Jamuna River. The suspended sediment data would be collected from IWM at Sirajganj Hard Point to Dhaleswari offlake as available on "Capital Pilot Dredging" project. The erosion and deposition processes on the river bed can be described by the two dimensional continuity equation changes in sediment concentration, as it was observed that the adaptation of the suspended sediment transport plays an important role in changing the bed topography. To predict the location of erosion and deposition on the river bed a number of measurements during the year 2012 survey are used for estimating the depth average velocity, water depth and concentration of suspended sediment. In this study two prediction methods are used for estimating the erosion and deposition processes on river bed. These methods are classified as Method-I (depth-velocity relation) and Method-II (depth-velocity and sediment concentration relation).

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Physical observation and analysis

River bank erosion is a severe problem in Bangladesh especially along the braided Jamuna River considering both the scale and intensity of erosion. Thousand hectares of floodplain are eroded each year and many people homeless with damaging infrastructures. Because of the dynamic nature, it causes the sufferings to the people along with damages to public and natural resources. To prevent bank erosion, different types of protective structures have been constructed at the erosion prone areas. The structural measures are sometimes ineffective due to changes of the river morphology. The data analyses for this study are as follows:

- Satellite image analysis
- Cross-section comparison
- Analyses of sediment concentration and depth average velocity

5.1.1 Satellite image analysis

The main channel of the Jamuna River is flowing parallel to the Sirajganj Hardpoint along the western side and then bifurcated at the downstream of the Hardpoint. From the dry season ASTER (2007) and IRS LISS (2008, 2009, 2010, 2011 and 2012) images represent that many sandbars are present at the upstream and beside the study bend. These sandbars are different size and shape and bars are translating both laterally and longitudinally at different rate. Their translation processes are described in the following sections

5.1.2 Sand bar translation

Bar dynamics relate to the morphologic behavior of rivers and in particular to the bank erosion processes. To understand the dynamics of the morphology such as large scale sand bars, a time series satellite image analysis has been conducted. Six geo-referenced ASTERS, IRS LISS images of 2007 to 2012 have been superimposed to assess the channel shifting and sand bar movements over the years. The sand bars at the upstream and adjacent to the study area are referred as sandbar 1 and sandbar-2 (Figure 5.1,

Figure 5.2 and Figure 5.3) respectively. In these analyses, lateral translation in each year was measured from the centerline of the 2007 bar towards the western direction. entually, longitudinal translation was measured from the head end of sand bar of 2007 towards the downward direction.

Figure 5.1: The sandbar movements of Jamuna River from 2007 to 2010.

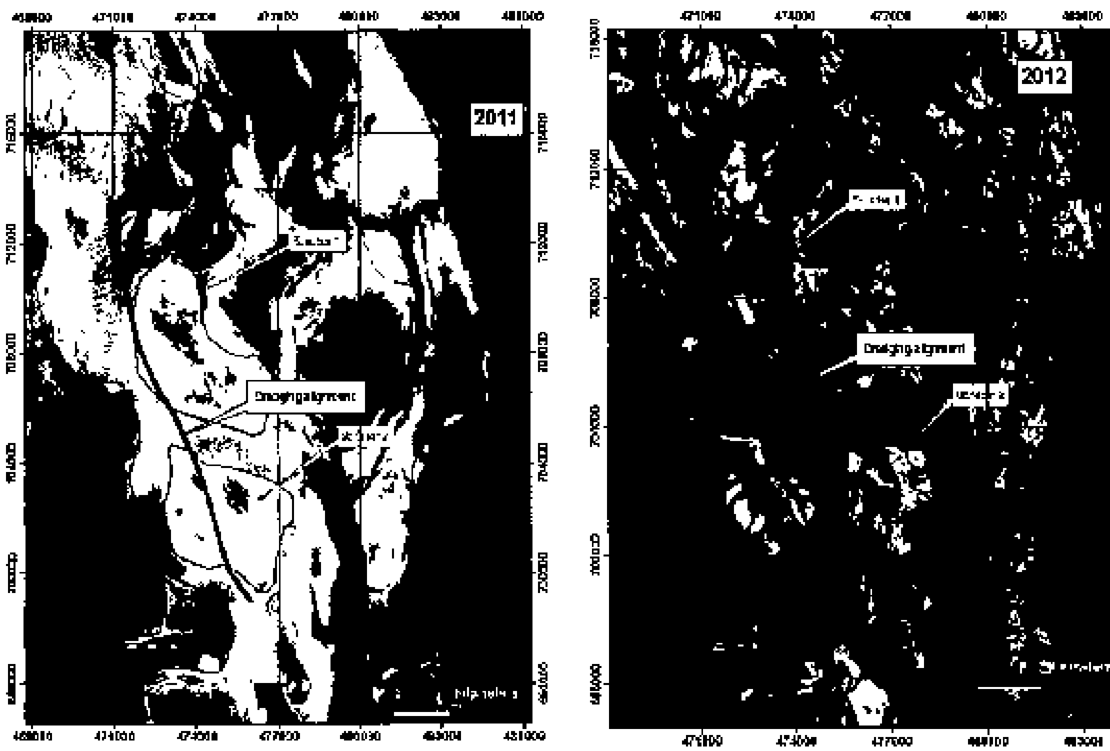


Figure 5.2: The sandbar movement of Jamuna River from 2011 to 2012.

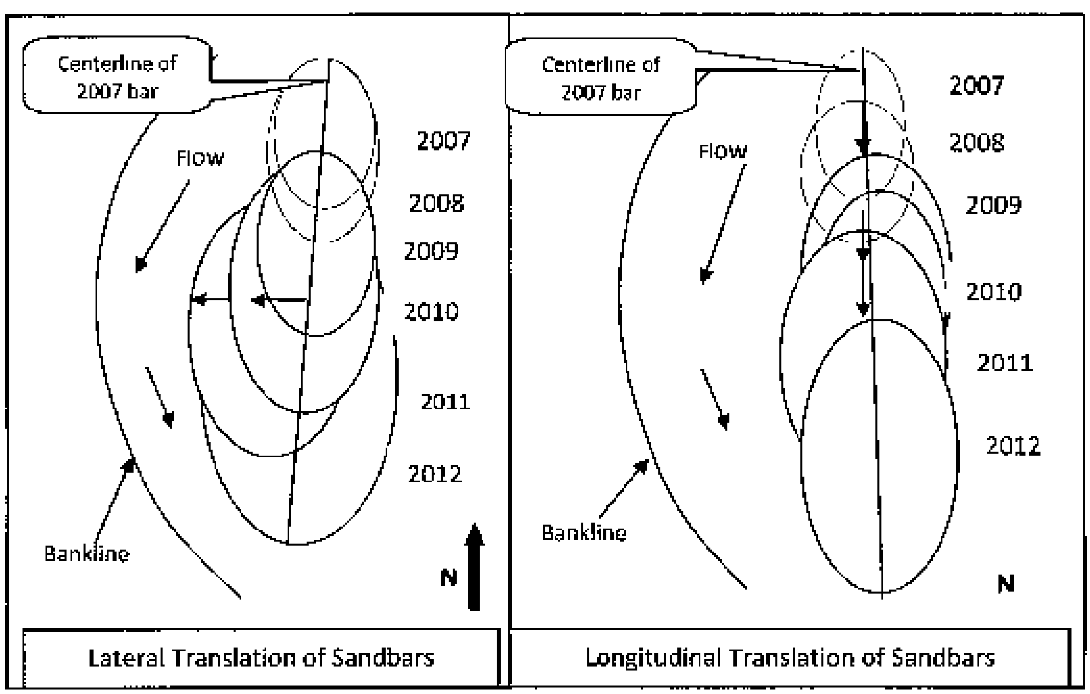


Figure 5.3: Schematic diagrams of lateral and longitudinal translation of bars. (Source: Fazana Mahmud, M.Sc thesis, 2011)

5.1.3 Lateral translation

During 2007 to 2009 both sandbars extended gradually along western side but after that, the extension was reduced 2010 to 2012 listed in Table 5.1 and shown in Figure 5.4. The reason for the variation of lateral extension was differ for bar-1 and bar-2. In case of sandbar-1, the western side revetment structure (Sirajganj Hardpoint) made obstruction to extend the bar and divert the flow to erode the west part of sandbar-1. And for sandbar-2, due to upstream revetment the bar could not manage enough sediment to extend at that section. Rather it washed away and deposited sediment downstream of the sandbar-2. Also the rate of extension of sandbar-1 was higher than sandbar-2, resulting sandbar-1 had got upstream sediment but Sirajganj Hardpoint constrained the bank erosion and sediment availability of sandbar-2.

The maximum lateral translation of sandbar-1 was occurred during 2007 and 2008 which was just upstream of the upstream termination of Sirajganj Hardpoint. In 2009 and 2010 bar was translated downstream from the upstream termination which caused damages of the hardpoint downstream from the termination. The west ward translation of the sandbar-1 diverted the flow towards the Hardpoint structure and caused undermining and damages during different years. Due to the position of sandbar-2 in 2007 a very narrow channel (100 to 150m) was flowing through between Sirajganj Hardpoint to Bangabandhu Bridge Guide Bundh. Due to lateral translation, flow was diverted by the sandbar-2 extreme west point towards the bank and by eroding the bank, the bend consequently developed.

Table 5.1: Changes in lateral translation of the sandbars

Year	Sandbar-1 in (m)	Sandbar-2 in (m)
2007	1540	730
2008	1690	910
2009	1870	1060
2010	1360	560
2011	1100	720
2012	800	680

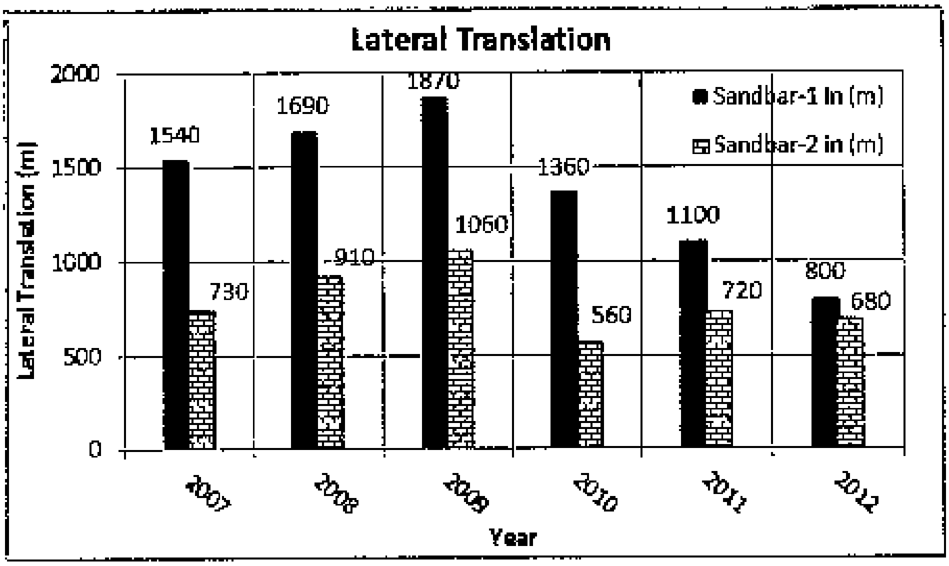


Figure 5.4: Lateral translation of the sandbar-1 and sandbar-2.

5.1.4 Longitudinal translation

Sandbars are also moving towards longitudinal direction. Longitudinal movement is measured as a distance travelled by the upstream end of the bar towards the downstream direction in the consecutive years. The longitudinal translation of sandbar-1 and sandbar-2 during 2007-2012 is listed in Table 5.2 and shown in Figure 5.5. During 2007 to 2012, sandbar-1 translated 150 to 600 meter per year and sandbar-2 moved 300 to 1400 meter per year. The rate of movement of sandbar-2 is higher than that of sandbar-1 because sandbar-1 was obstructed by the revetment structure as well sandbar-2 could move downstream without facing any obstacle. In 2010 and 2012, sandbar-2 diverted flow towards downstream bend and caused huge erosion at the downstream part of the bend. As a whole, due to the translation of sandbars along downstream, flows were diverted towards the bank and caused bank erosion.

Table 5.2: Changes in longitudinal translation of the sandbars

Year	Longitudinal translation of sandbar-1 in (m)	Longitudinal translation of sandbar-2 in (m)
2007	0	0
2008	650	1400
2009	800	1800
2010	1300	2200
2011	1950	2500
2012	2100	3500

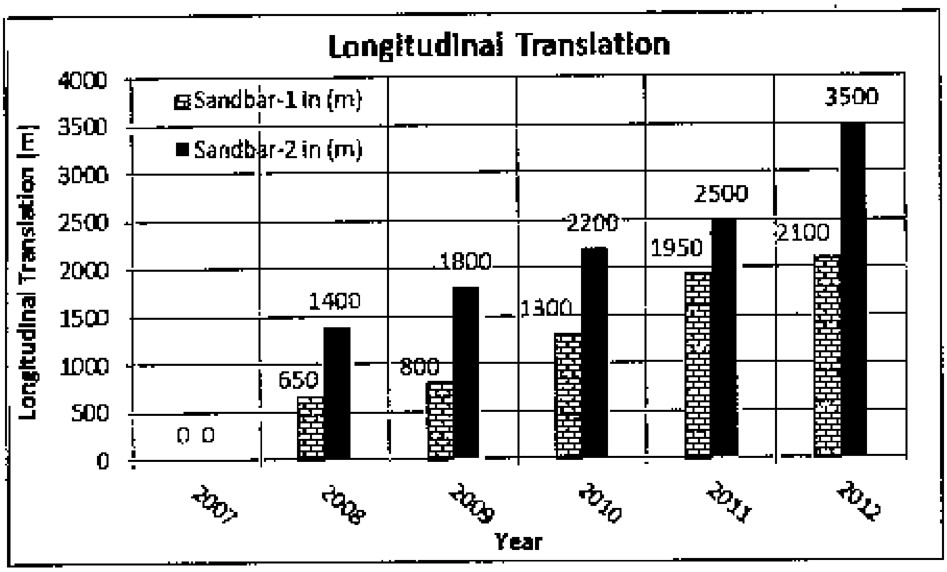


Figure 5.5: Longitudinal translation of the sandbar-1 and sandbar-2.

Summary results from satellite image analysis: Satellite image analysis (Figure 5.1 and Figure 5.2) indicates that the flow processes and the location of active bank erosion significantly changes due to changes in the large scale sand bar movement (both laterally and longitudinally). Bar dynamics are related to the morphological behavior of rivers. In particular cases bar dynamics are also related to the bank erosion processes and the prevailing trends of flow processes of rivers. The magnitude and direction of near bank flow at bends accelerate the erosion processes. The near bank flow process is governed by the dry season and to some extent at the beginning of the rising stage. The large scale bed features such as sand bars are the major flow guiding factor towards bank line and channel shifting. Due to translation of sandbars along downstream (Figure 5.3, Figure 5.4 and Figure 5.5), flow was diverted towards the bank and caused bank erosion. The channel is developing very fast along the western bank of the Jamuna River.

5.2 Cross sections comparison

Most of the rivers of Bangladesh demonstrate a high and a low water period synchronizing with the monsoon and the dry seasons respectively. Streams are very broadly classified as meandering, straight/transitional and braided. Braided and meandering patterns represent extremes in a continuum of channel patterns. The planform geometry of a stream is determined by the interaction of numerous variables and one should anticipate observing a complete range of channel patterns in most river systems. Bathymetric data were collected from BWDB in connection with Pilot Capital

Dredging Project within 2010 to 2013. The location map around the study area is shown in (Figure 3.1). The bathymetric data were plotted 6 (six) locations within the study reach to see the changing pattern of bed level elevation. The cross-section comparisons around the study area are shown in (Figure 5.6 to Figure 5.11).

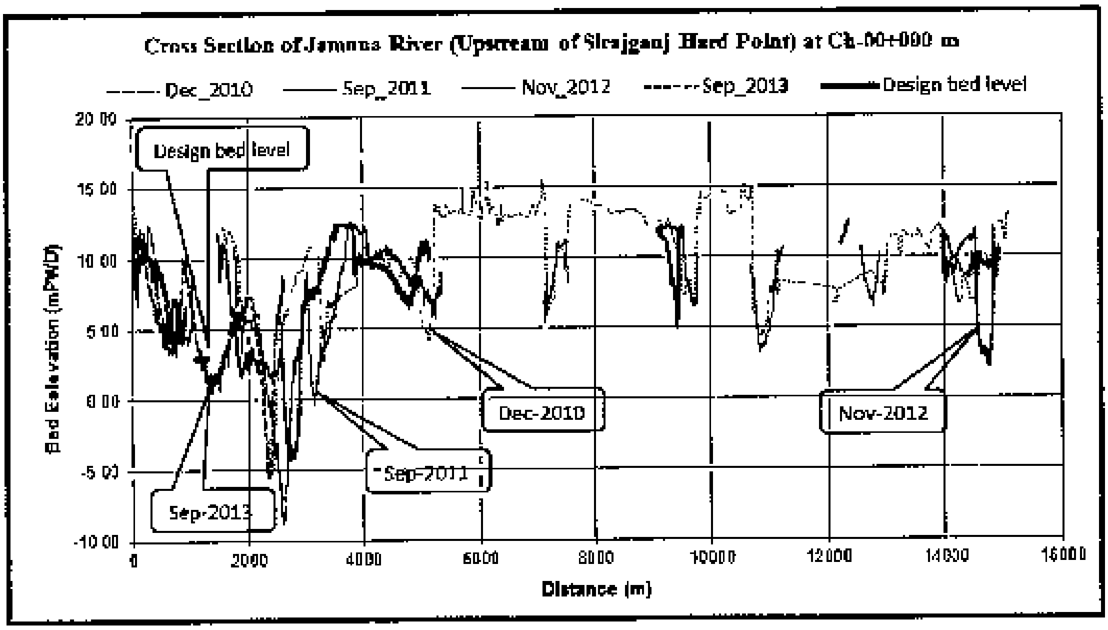


Figure 5.6: Cross-sections of Jamuna river at upstream of Sirajganj Hardpoint.

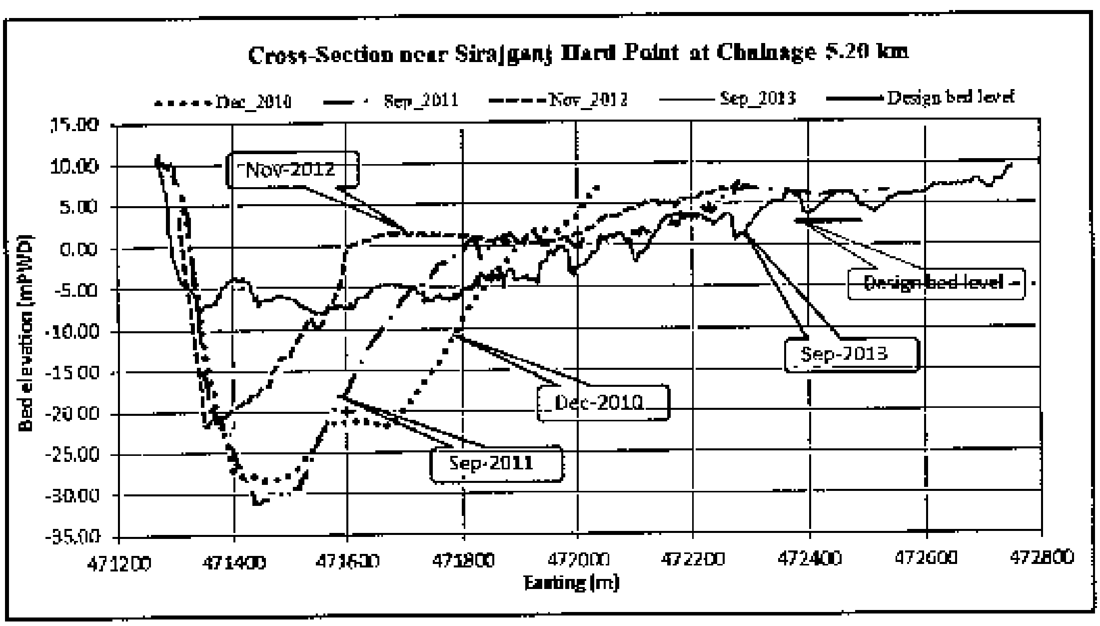


Figure 5.7: Cross-sections of Jamuna River near Sirajganj Hardpoint.

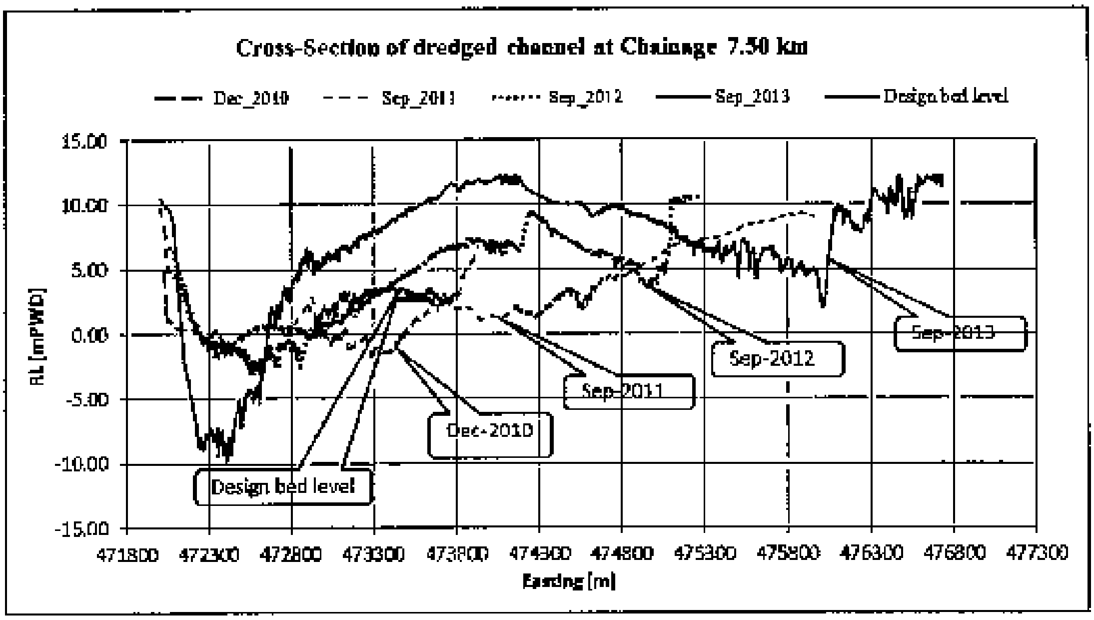


Figure 5.8: Cross-sections of Jamuna River along dredge channel.

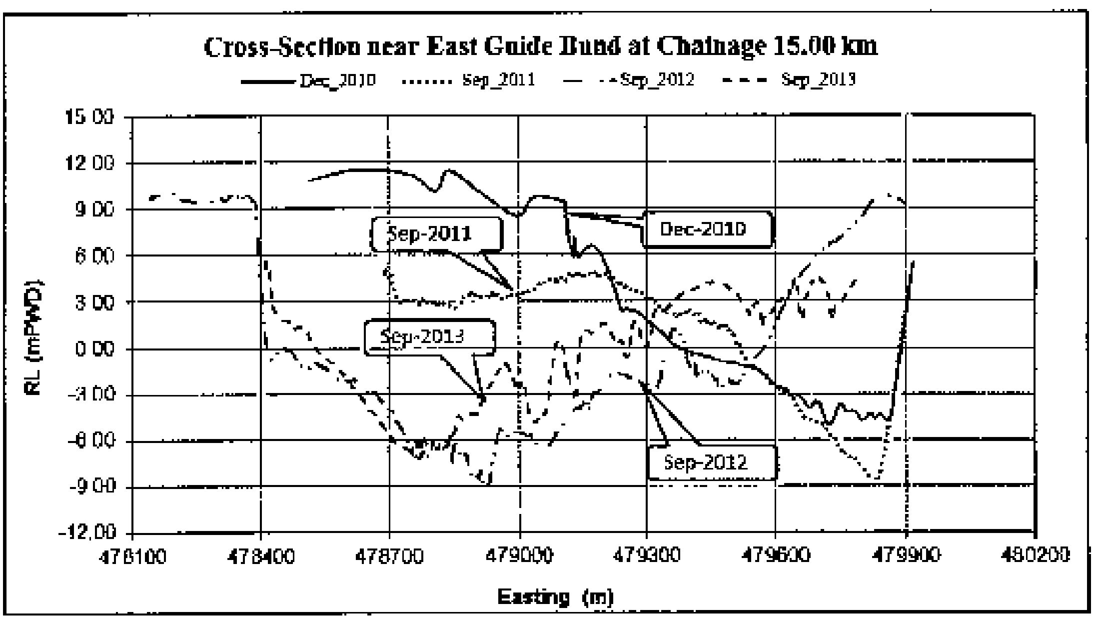


Figure 5.9: Cross-sections of Jamuna River neal East guide bundhh.

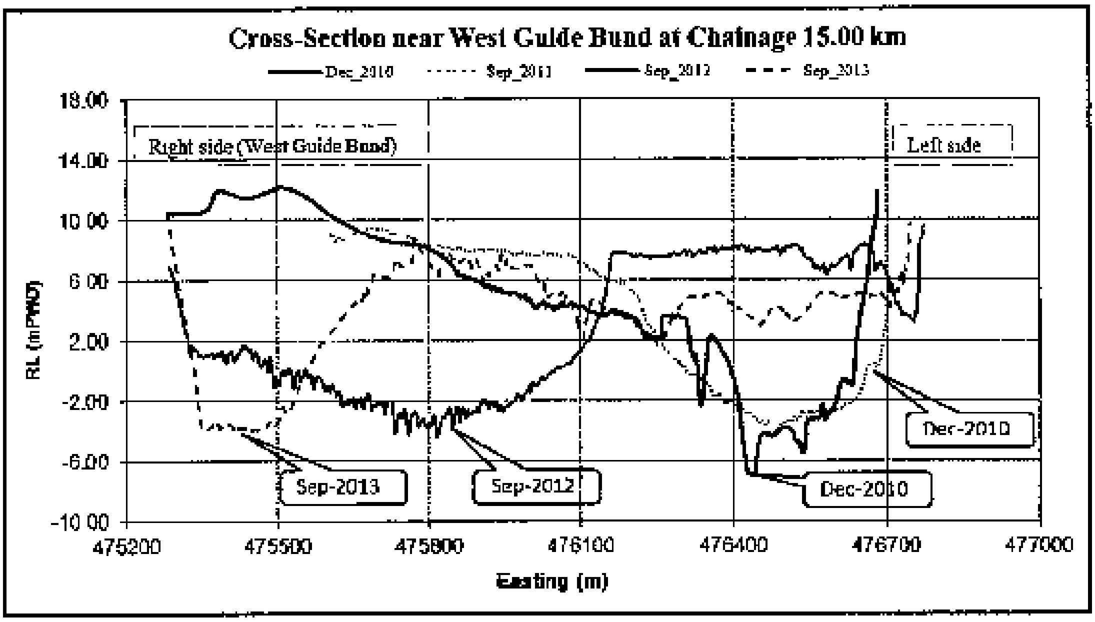


Figure 5.10: Cross-sections of Jamuna River neat West guide bundhh.

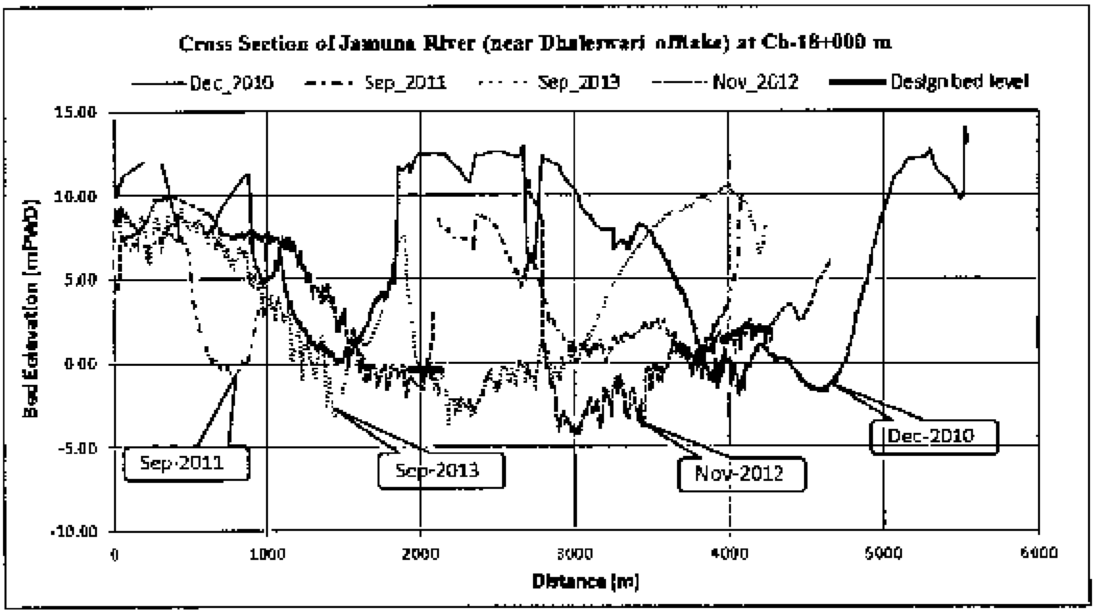


Figure 5.11: Cross-sections of Jamuna River near downstream of Bangabandhu Bridge.

Summary results from cross-section comparison: Cross-section data has been plotted at six locations, shown in (Figure 5.6 to Figure 5.11) from upstream of Sirajganj Hardpoint to downstream of Bangabandhu Bridge near Dhaleswari offtake. These cross-section data which is plotted is from the year 2010 to 2013, because pilot capital dredging was implemented on 2011-2012. Figure 5.6 and Figure 5.7 represents, insignificant impact of dredging is observed at upstream of Sirajganj Hardpoint as well as the Sirajganj Hardpoint area. Figure 5.7 also represent, a minor rate of sedimentation is observed around Sirajganj Hardpoint area during implementation of dredging. At that time, the scour depth at Sirajgonj Hardpoint was reduced up to maximum 5m. However, it seems that dredging would help to reduce scour depth around Bangabandhu Bridge guide bundh and it would provide safety to the guide bundh for a very short period.

The observed data were analyzed and evaluated. Initially the flow was diverted to the dredged channel about 12.50% (source: IWM, 2013). Figure 5.8 represent, after one year of monsoon flooding, it is quite difficult to trace the dredged channel. It has been found that the dredged channel silted up to 60%-80%. It also appear that the siltation rate is higher, where the dredging alignment passing through the char. Figure 5.9 and Figure 5.10 represents the changing bed profile of the East Guide Bundh and West Guide Bundh. In the vicinity of East Guide Bundh of Bangabandhu Bridge, it has been found that, the siltation rate is higher near bank channel, whereas a new channel has been propagated at 1 km west of the bundh by eroding the existing low char.

The cumulative backfill percentage was found to be around 28% from downstream of Bangabandhu Bridge to Dhaleswari offtake (Source: IWM, 2013). Figure 5.11 represents, insignificant positive impact of dredging is found at D/S of Bangabandhu Bridge near Dhaleswari Offtake, because during implementation of dredging we cannot change the upstream river morphology as well as the hydraulic condition of the dredged channel.

5.3 Analyses of sediment concentration and depth average velocity

5.3.1 Background of the analysis

Braided rivers are strongly influenced by high sediment delivery from nearby sources coupled with lower sediment transport capacity due to hydraulic conditions (primarily gentle slopes). They are sensitive to changes in their flood regime or sediment influx and can completely modify their geometry over a few decades (Ferguson, 1993). Common braided river adjustments to changing environmental conditions typically include both narrowing and widening. Moreover, rivers can shift from other planforms to a braided pattern when human activities accelerate sediment delivery processes. At the same time, climatic conditions and human influences that reduce sediment production can have the opposite effect with braiding slowly diminishing through time. Thus the dynamic nature of braided rivers makes it difficult for societies to both predict the direction of their evolution and maintain nearby and associated infrastructure. Braided channels are rarely in a steady state and are indicative of a valley bottom still actively undergoing construction. In undeveloped floodplain areas, braided rivers are considered part of the natural environment and are typically preserved because of their associated ecological richness. However, when permanent infrastructure is built in such active floodplains many problems can occur.

Riverbank erosion is one of the most unpredictable and critical type of disasters that takes into account the quantity of rainfall, soil structure, river morphology, topography of river and adjacent areas and floods. The dynamic character of the braided channeled river and the failure of structural measures, the sufferings of the people continue. Long-term policies and strategies should be taken to cope up with bank erosion taking into account the social and institutional adjustment measures. Spatial variation of sediment transport in an alluvial sand-bed river bend needs to be understood with its influencing factors such as bank erosion, secondary current formation, land spur and bed-material characteristics. In this study, detailed hydrographic surveys with Acoustic Doppler Current Profiler (ADCP) were conducted at 9 (nine) locations to measure suspended load, velocity, bathymetric profile and characteristics of the bed material. Using the above parameters, the spatial and temporal variation of erosion or deposition processes has been assessed. With due end of discussed below (FAP 24, 1996).

A number of prediction methods are available for predicting the changes of the various morphological conditions In this study two prediction methods are using for estimating the erosion and deposition processes on river bed. These methods are classified by:

5.3.2 Method-1 (depth-velocity relationship)

The erosion and deposition processes on the river bed can be described by the two dimensional continuity equation changes in sediment concentration, as it was observed that the adaptation of the suspended sediment transport plays an important role in changing the bed topography To predict the location of erosion and deposition on the river bed a number of measurements during the year 2012 survey are used for estimating the depth average velocity and water depth (FAP 24, 1996). During 2012 survey ADCP was used for number of river reaches hence both parameters are available. Instead of a linear relation between the water depth and the velocity, for the Jamuna River the relation between velocity and square root of the depth yields a good demarcation line between the erosion deposition areas.

The observed erosion and deposition in relation to depth and velocity is the result of a combination of different processes and is in principle based on physical laws. One probable explanation for getting this type of relation is that the involved process is an adaptation process The bed topography (cross-section) is relating behind the flow pattern. It is trying to adjust to changing conditions flow by eroding and depositing on riverbed. The prediction method for erosion and deposition represented by the following equations:

Erosion $u > \sqrt{h} - 1.35$ -- (5.1)

Transition: $\sqrt{h} - 1.35 \leq u \leq \sqrt{h} - 1.65$ -------------------------- (5.2)

Deposition: $u < \sqrt{h} - 1.65$ -- (5.3)

Where, h = water depth in meter and u = depth average velocity in m/sec. Transition is defined as erosion/deposition < 1.0 m.

This short term prediction method can be applied for assisting in the maintaining the dredging alignment in the Jamuna River, as it can give indications where dredging might be effective. The short term prediction can be useful for estimating the requirement of dredging and it can assist in making decision as to the best location and alignment of dredging work. The net erosion and net deposition in downstream direction can be related to the average velocity and average depth over the cross-section. The location map for data collection and analysis of field measured data has been summarized in Table 5.3 and explained through Figure 5.12 ~ Figure 5.21.

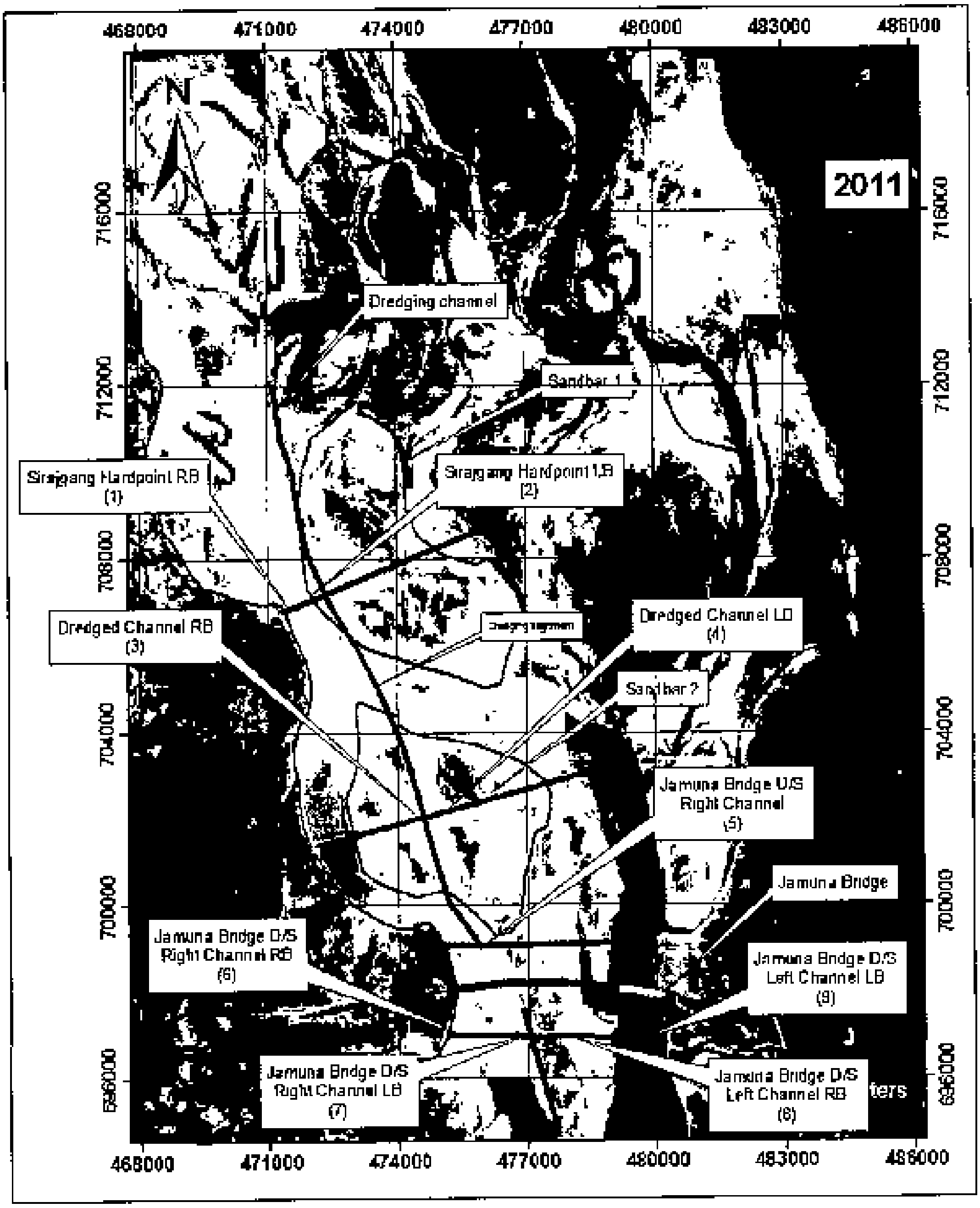


Figure 5.12: Map showing the sediment concentration and velocity measurement locations of Jamuna River around the study area.

Table 5.3: Depth of water and depth average velocity at different dates around the study area.

Sample location	Date	Depth of water (m)	Sqrt. Depth (m)	Depth average velocity (m/S)
Sirajganj Hardpoint RB (Ref. Figure 5.12)	26-Apr-12	12.17	3.5	1.15
	5-Jun-12	16.35	4.0	1.26
	16-Jun-12	18.50	4.3	2.10
	20-Jun-12	17.56	4.2	2.27
	26-Jun-12	16.75	4.1	2.31
	9-Jul-12	18.80	4.3	2.40
	30-Jul-12	20.93	4.6	1.53
	12-Sep-12	12.00	3.5	1.13
	27-Sep-12	14.30	3.8	1.78
	9-Oct-12	12.50	3.5	1.89
	9-Oct-12	7.50	2.7	2.28
	9-Oct-12	11.34	3.4	2.25
	21-Oct-12	13.00	3.6	0.54
	21-Nov-12	9.50	3.1	0.79
	21-Dec-12	15.63	4.0	0.31
Sirajganj Hardpoint LB (Ref. Figure 5.12)	26-Apr-12	5.87	2.4	0.19
	5-Jun-12	5.29	2.3	1.23
	16-Jun-12	5.00	2.2	1.44
	20-Jun-12	4.56	2.1	1.87
	26-Jun-12	5.80	2.4	1.96
	9-Jul-12	7.00	2.6	1.51
	9-Jul-12	9.50	3.1	1.89
	17-Jul-12	7.66	2.8	1.68
	17-Jul-12	10.15	3.2	1.35
	24-Jul-12	12.86	3.6	1.85
	30-Jul-12	11.80	3.4	1.42
	12-Sep-12	8.50	2.9	1.29
	27-Sep-12	10.20	3.2	1.83
	9-Oct-12	7.50	2.7	2.28
	21-Oct-12	7.56	2.7	1.53
	21-Nov-12	4.00	2.0	0.55
	21-Dec-12	3.70	1.9	1.26
	21-Dec-12	4.79	2.2	0.61
Dredged channel RB (Ref. Figure 5.12)	05-06-12	5.96	2.4	2.78
	16-06-12	4.50	2.1	2.52
	16-06-12	5.30	2.3	2.39
	20-06-12	6.00	2.4	2.86
	20-06-12	6.50	2.5	2.61
	27-06-12	10.00	3.2	2.25
	27-06-12	7.50	2.7	2.77
	09-07-12	5.50	2.3	1.66

Sample location	Date	Depth of water (m)	Sqrt. Depth (m)	Depth average velocity (m/S)
	17-07-12	6.53	2.6	1.13
	17-07-12	5.13	2.3	2.50
	27-09-12	4.11	2.0	1.25
	09-10-12	6.00	2.4	1.93
	21-10-12	4.27	2.1	0.52
Dredged channel LB (Ref. Figure 5.12)	26-04-12	9.43	3.1	1.77
	26-04-12	11.63	3.4	1.37
	26-04-12	10.60	3.3	1.63
	24-07-12	9.64	3.1	1.54
	12-09-12	10.80	3.3	2.10
	12-09-12	8.50	2.9	1.50
	27-09-12	9.56	3.1	1.71
	09-10-12	10.00	3.2	1.66
	21-10-12	9.74	3.1	1.78
	21-11-12	6.20	2.5	1.03
	21-11-12	3.80	1.9	0.77
	21-12-12	5.29	2.3	0.52
	21-12-12	3.62	1.9	0.67
JMB US right channel RB (Ref. Figure 5.12)	16-06-12	5.66	2.4	2.55
	16-06-12	8.22	2.9	1.70
	20-06-12	5.90	2.4	2.60
	27-06-12	6.30	2.5	3.04
	27-06-12	8.50	2.9	1.38
	30-07-12	12.66	3.6	1.88
	30-07-12	17.04	4.1	1.55
	17-07-12	6.17	2.5	1.99
	24-07-12	9.70	3.1	1.76
	30-07-12	13.43	3.7	1.49
	12-09-12	9.50	3.1	1.30
	27-09-12	7.50	2.7	1.37
	09-10-12	11.70	3.4	1.29
	21-10-12	8.93	3.0	1.70
	21-11-12	6.50	2.5	0.53
	21-11-12	3.40	1.8	0.37
	21-12-12	5.02	2.2	0.67
	21-12-12	8.63	2.9	0.60
JMB DS right channel LB (Ref. Figure 5.12)	26-04-12	8.36	2.9	0.34
	26-04-12	9.57	3.1	0.34
	05-06-12	6.49	2.5	0.81
	05-06-12	8.50	2.9	1.71
	16-06-12	10.69	3.3	2.04
	16-06-12	11.44	3.4	1.98
	20-06-12	9.62	3.1	1.42

Sample location	Date	Depth of water (m)	Sqrt Depth (m)	Depth average velocity (m/S)
	20-06-12	10 06	3.2	2.55
	27-06-12	6.80	2.6	2 45
	27-06-12	7.70	2.8	2 12
	27-06-12	5.00	2.2	2 65
	09-07-12	7.00	2.6	2 87
	09-07-12	10.00	3.2	2 54
	17-07-12	11.59	3.4	1 90
	24-07-12	14.58	3.8	1 88
	30-07-12	12.90	3.6	0 71
	12-09-12	4.00	2.0	0 72
	27-09-12	13.20	3.6	2 01
	09-10-12	4.00	2.0	1.42
	21-10-12	3.26	1 8	0.80
JMB DS left channel RB (Ref. Figure 5 12)	05-06-12	7.30	2.7	1.71
	16-06-12	4.50	2.1	1.73
	20-06-12	8 00	2 8	1 61
	28-06-12	7.50	2.7	2.62
	28-06-12	9.30	3.0	2 24
	09-07-12	8.54	2.9	1 98
	17-07-12	8.77	3.0	2.81
	24-07-12	12.50	3.5	2 87
	30-07-12	8.00	2.8	0 89
	12-09-12	14.00	3.7	1.49
	27-09-12	16.00	4.0	1.62
	09-10-12	15.20	3.9	1 70
	21-10-12	14.71	3.8	1.29
	21-12-12	4.62	2.1	0.36
JMB DS left channel LB (Ref. Figure 5 12)	26-04-12	11 36	3 4	1.81
	05-06-12	11.60	3.4	1.76
	05-06-12	9.00	3 0	1.22
	16-06-12	9.53	3.1	1.13
	20-06-12	13.80	3.7	2 20
	28-06-12	5 90	2.4	1.30
	09-07-12	10.12	3.2	2 26
	17-07-12	4.86	2.2	1.36
	24-07-12	8.51	2.9	2 93
	30-07-12	8.00	2 8	1.83
	12-09-12	3 40	1.8	0.08
	27-09-12	3 20	1.8	1.53
	09-10-12	4.60	2 1	1.55
	21-10-12	7 35	2.7	0.87
	21-11-12	8 40	2.9	0 30
	21-12-12	7.94	2 8	0 40

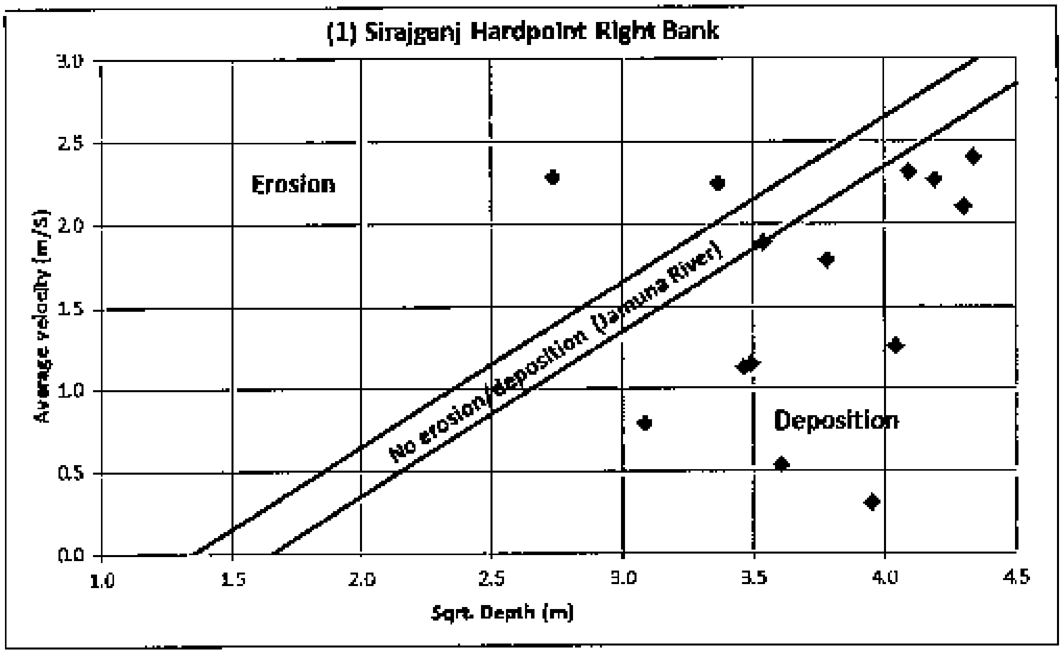


Figure 5.13: Erosion and deposition on the riverbed at Sirajganj Hardpoint right bank of Jamuna in period April, 2012 to January, 2013.

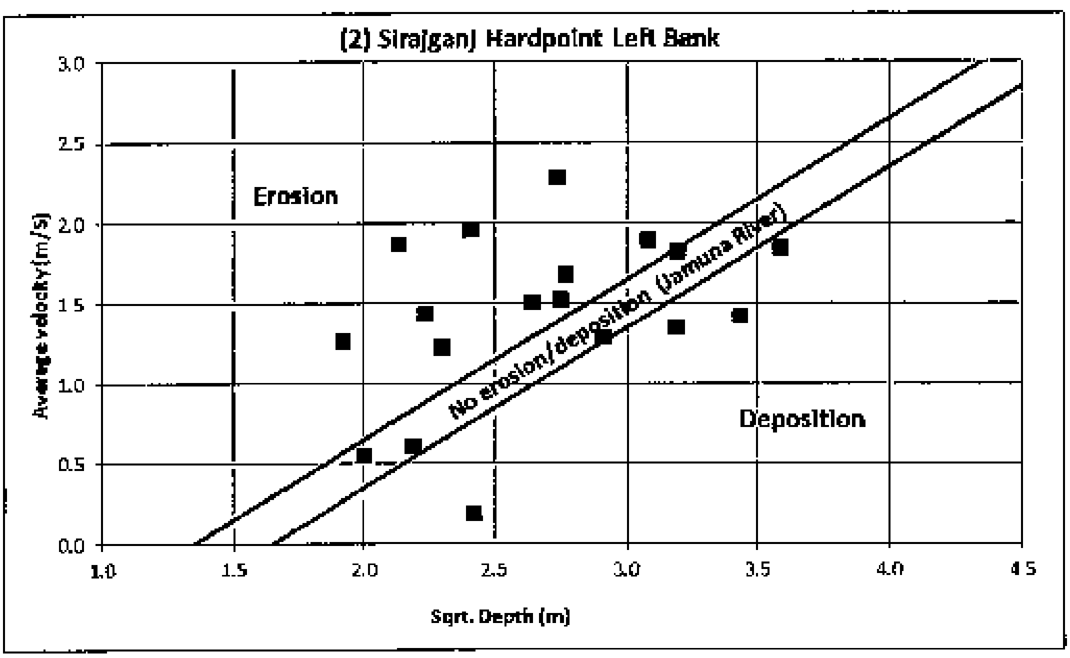


Figure 5.14: Erosion and deposition on the riverbed at Sirajganj Hardpoint left bank of Jamuna River in period April, 2012 to January, 2013.

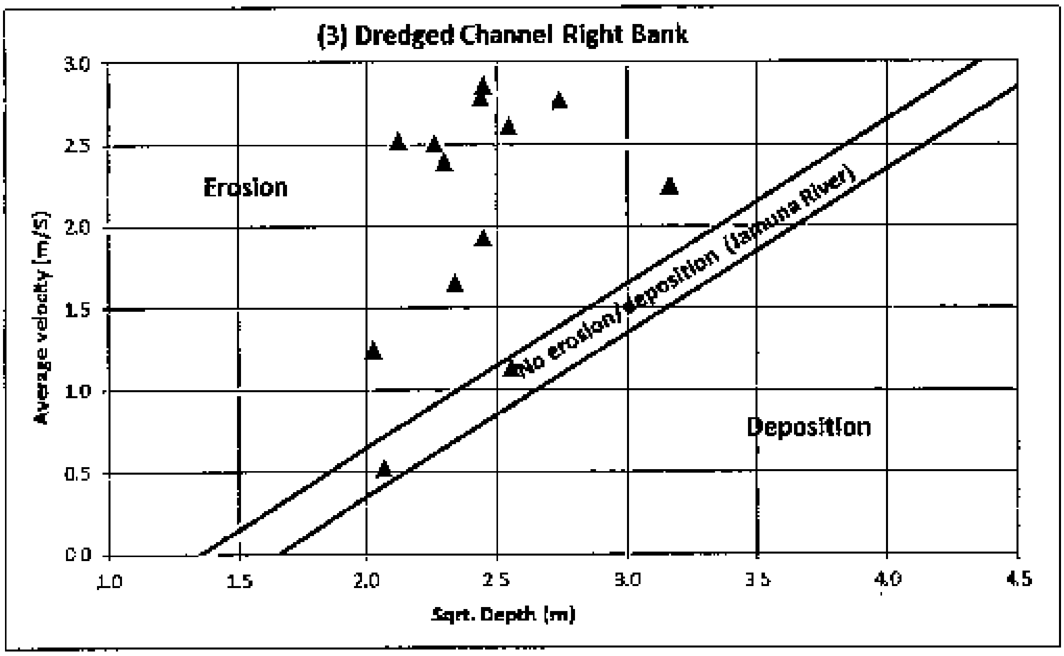


Figure 5.15: Erosion and deposition on the riverbed at dredged channel right bank of Jamuna River in period May to November, 2012.

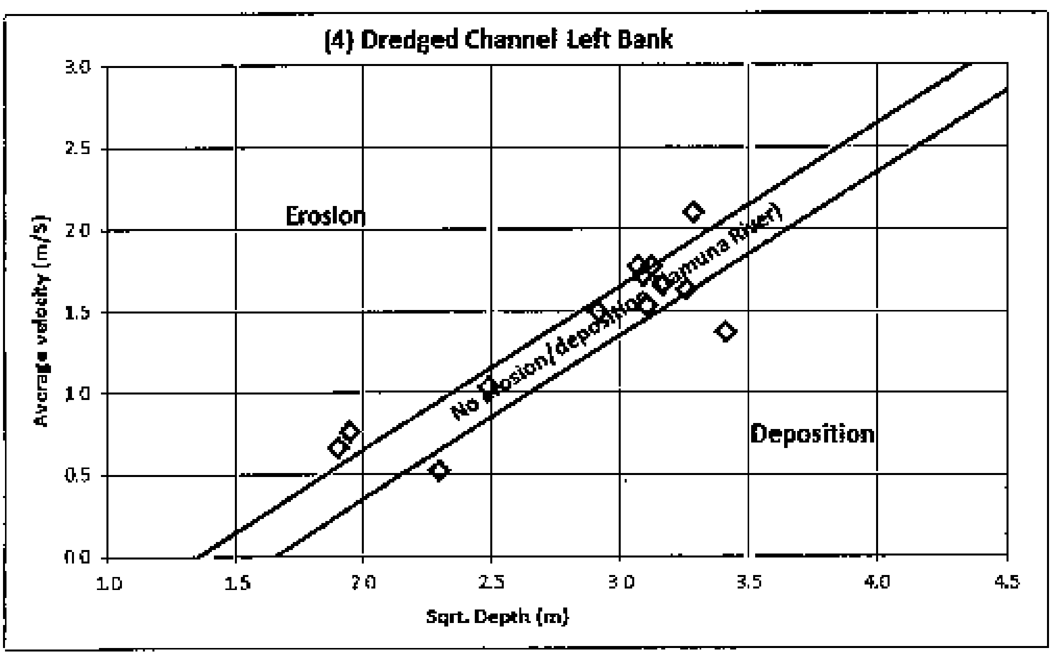


Figure 5.16: Erosion and deposition on the riverbed at dredged channel left bank of Jamuna River in period April, 2012 to January, 2013.

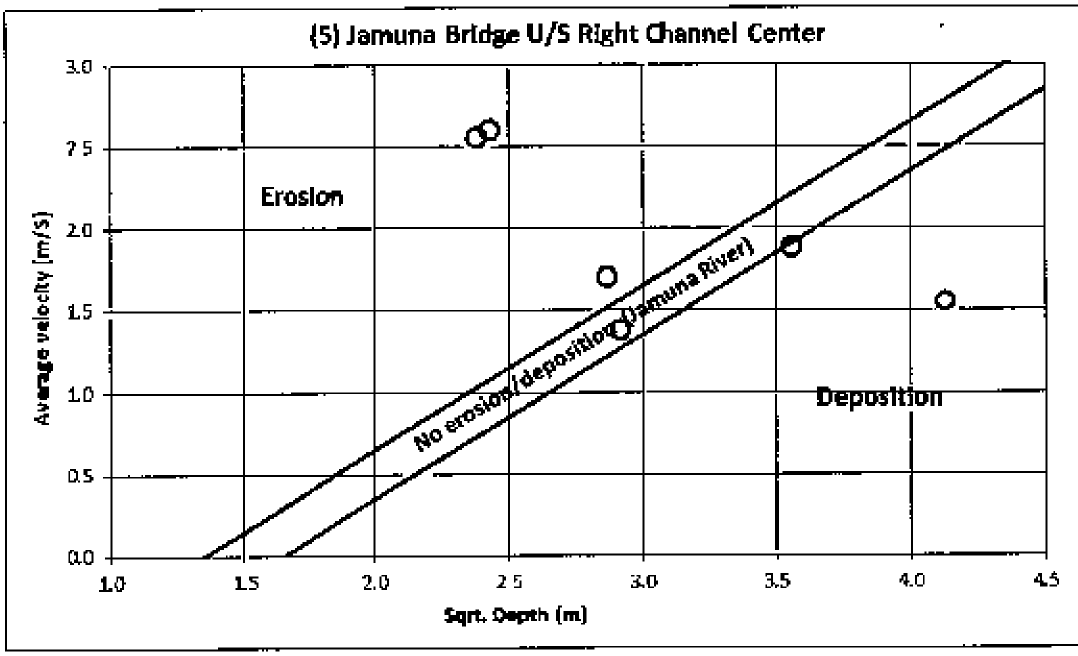


Figure 5.17: Erosion and deposition on the riverbed at Bangabandhu Bridge right channel center of Jamuna River in period June-August, 2012.

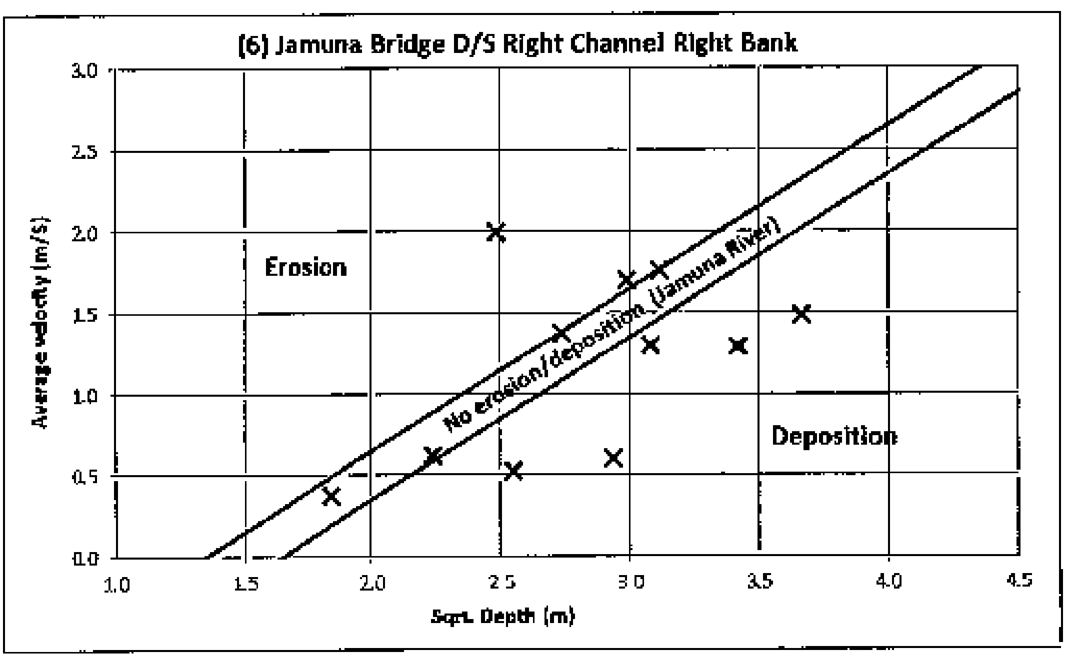


Figure 5.18: Erosion and deposition on the riverbed at Bangabandhu Bridge D/S right channel right bank of Jamuna River in period June, 2012 to January, 2013.

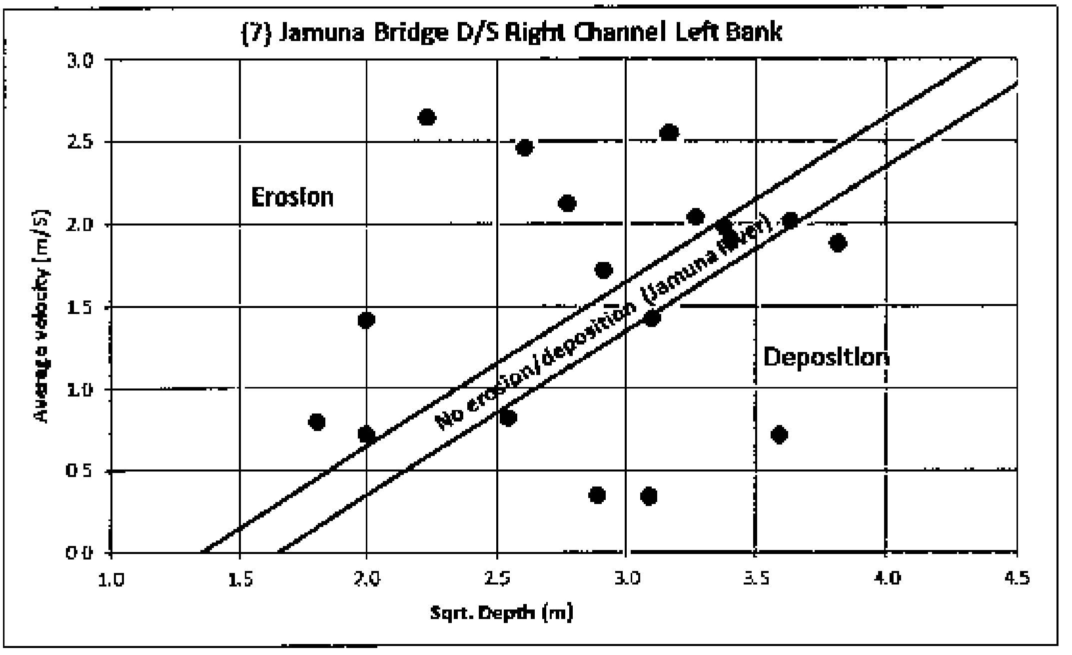


Figure 5.19: Erosion and deposition on the riverbed at Bangabandhu Bridge D/S right channel left bank of Jamuna River in period April-November, 2012.

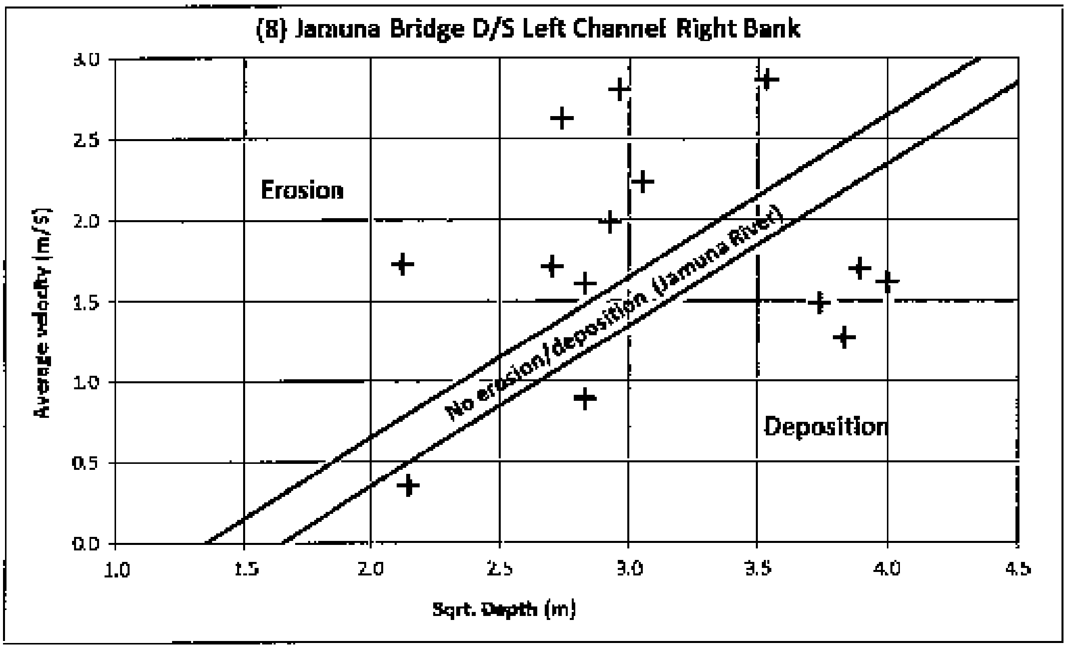


Figure 5.20: Erosion and deposition on the riverbed at Bangabandhu Bridge D/S left channel right bank of Jamuna River in period May, 2012 to January, 2013.

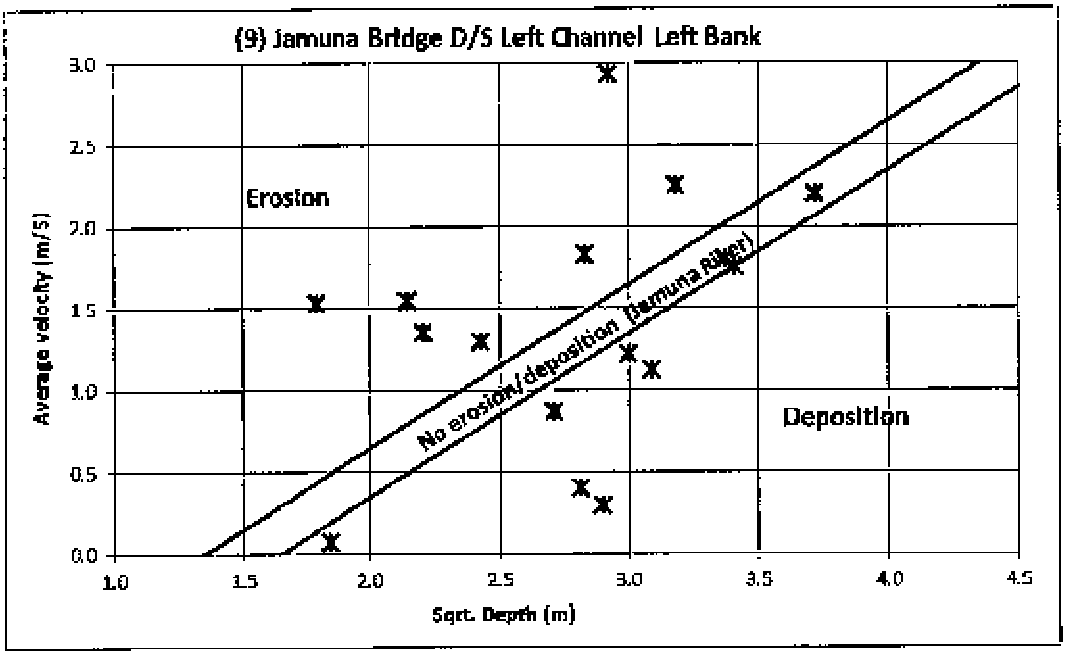


Figure 5.21: Erosion and deposition on the riverbed at Bangabandhu Bridge D/S left channel left bank of Jamuna River in period April, 2012 to January, 2013.

Observation form method I (depth-velocity relationship) represented by:

- Figure 5.13 and Figure 5.14 shows the erosion and deposition on Sirajganj Hardpoint right bank and left bank of Jamuna River. Figure 5.13 represents that the right bank of Sirajganj Hardpoint is favorable for sedimentation on the same time Figure 5.14 represents that the left bank is favorable for erosion. It is happening due to the position of sandbars at upstream of Sirajganj Hardpoint.

- Figure 5.15 indicates the erosion at the dredged channel right bank, on the same time Figure 5.16 indicates; there is no change at dredged channel left bank. It is happening, because the dredging alignment passing through the high char at that location.

- Figure 5.17 indicates erosion at the right channel of the upstream of Bangabandhu Bridge in the monsoon but in dry season it indicates deposition. It is happening, because at the upstream of Bangabandhu Bridge the main flow of Jamuna River passing through this channel in monsoon.

- Figure 5.18 represents, most of the time the Bangabandhu Bridge D/S right channel right bank indicates deposition, on the same time Figure 5.19 represents, most of the time the Bangabandhu Bridge D/S right channel left bank indicates erosion. At the downstream of Bangabandhu Bridge the river is bifurcating by right channel and left channel. It is happening due to presence of high char at left side of the right channel

- Figure 5.20 represents, most of the time the Bangabandhu Bridge D/S left channel right bank indicates erosion in monsoon and deposition in dry season, on the same time Figure 5.21 represents, most of the time the Bangabandhu Bridge D/S left channel left bank indicates erosion but few time its indicates deposition. It is happening because the maximum discharge in monsoon passing through this channel and sandbar presence at the right side of left channel at the downstream of Bangabandhu Bridge.

5.3.3 Method-II (Depth-velocity & sediment concentration relationship)

To better understand the sediment transport processes in the river, nine points are selected at four locations in the Jamuna River from Sirajganj Hardpoint to downstream of Bangabandhu Bridge near Dhaleswari Offtake. The predicted concentration corresponds to the sediment transport capacity using a sediment transport predictor specially developed for the Jamuna River. In estimating the sediment concentration instead of using the parameter θ, the depth average velocity is replaced by using Chezy's relation and the modified relation reads as:

$$c = \frac{80}{1-\varepsilon} \cdot \sqrt{\Delta g D_{50}^{3}} \cdot \left(\frac{1}{C^2 \Delta D_{50}}\right)^{1.8} \cdot \frac{u^{3.6}}{h} \text{ ------------------ (5.4)}$$

Where, c = depth-average concentration, Assuming $\Delta = 1.65$, $C = 70\ m^{1/2}/s$ and $D_{50} = 0.2$ mm. The following equation can be expressed as.

$$c = 1024 \cdot \frac{u^{3.6}}{h} \text{ -- (5.5)}$$

In which c is expressed as mg/l.

It is mentioned here that the roughness height for bed form not only depends on the bedforms height, but also very much depends on the shape of the bedform. This observation contradicts with the observation Lukanda et al (1992) and Klaassen et al (1988). To estimate the average roughness and sediment transport, the effect of the bedform during the high flow may not be relevant, but for particular locations it might have some influence in contributing the local roughness as well as to the sediment transport. Here it should be mentioned that apart from the high sediment concentration, there are some location where the bedform are also prominent. More detailed information on the shape, height and length of the dune and also about the flow may enable to elucidate the influence of bedforms on the sediment transport. The location map for data collection and analysis of field measured data has been summarized in Table 5.4 and shown in Figure 5.12, Figure 5.22 ~ Figure 5.30 respectively.

Table 5.4: Depth of water, actual sediment concentration and predicted sediment concentration at different dates around the study area

Sample location	Date	Depth (m)	Actual sediment concentration (mg/l)	Predicted sediment concentration (mg/l)
Sirajgonj Hard Point RB (Ref. Figure 5.12)	26-Apr-12	12.17	518	121
	5-Jun-12	16.35	206	113
	16-Jun-12	18.50	219	382
	20-Jun-12	17.56	533	489
	26-Jun-12	16.75	258	540
	9-Jul-12	18.80	578	531
	30-Jul-12	20.93	797	148
	12-Sep-12	12.00	408	117
	27-Sep-12	14.30	1114	322
	9-Oct-12	12.50	549	428
	21-Oct-12	11.34	520	739
	21-Nov-12	13.00	30	16
	21-Dec-12	15.63	98	3
Sirajgonj Hard Point LB (Ref Figure 5.12)	26-Apr-12	5.87	192	2
	5-Jun-12	5.29	255	329
	16-Jun-12	5.00	463	529
	20-Jun-12	4.56	287	1146
	26-Jun-12	5.80	378	1014
	9-Jul-12	7.00	527	427
	9-Jul-12	9.50	532	565
	17-Jul-12	7.66	909	512
	17-Jul-12	10.15	931	220
	24-Jul-12	12.86	308	393
	30-Jul-12	11.80	615	215
	12-Sep-12	8.50	404	233
	27-Sep-12	10.20	923	480

Sample location	Date	Depth (m)	Actual sediment concentration (mg/l)	Predicted sediment concentration (mg/l)
	9-Oct-12	7.50	476	1166
	21-Oct-12	7.56	592	408
	21-Nov-12	4.00	103	54
	21-Dec-12	4.79	69	60
Dredged Channel RB (Ref. Figure 5.12)	05-06-12	5.96	166	2452
	16-06-12	4.50	373	2524
	16-06-12	5.30	413	1859
	20-06-12	6.50	540	1906
	27-06-12	10.00	439	839
	27-06-12	7.50	403	1932
	09-07-12	5.50	503	690
	17-07-12	6.53	799	217
	17-07-12	5.13	863	2171
	27-09-12	4.11	1267	444
	09-10-12	6.00	749	943
	21-10-12	4.27	631	44
Dredged Channel LB (Ref. Figure 5.12)	26-04-12	11.63	491	200
	24-07-12	9.64	467	324
	12-09-12	10.80	347	655
	27-09-12	9.56	1366	435
	09-10-12	10.00	797	382
	21-10-12	9.74	589	467
	21-11-12	6.20	117	179
	21-12-12	5.29	106	36
Jamuna U/S Right channel center (Ref. Figure 5.12)	16-06-12	5.66	457	2061
	16-06-12	8.22	281	492
	20-06-12	5.90	500	2079
	27-06-12	6.30	501	2930
	27-06-12	8.50	266	277
	30-07-12	12.66	671	419
	30-07-12	17.04	401	189
Jamuna D/S Right Channel RB (Ref. Figure 5.12)	17-07-12	6.17	892	996
	24-07-12	9.70	719	460
	30-07-12	13.43	717	216
	12-09-12	9.50	251	212
	27-09-12	7.50	1062	311
	09-10-12	11.70	442	170
	21-10-12	8.93	276	456
	21-11-12	6.50	76	30
	21-11-12	3.40	123	23
	21-12-12	5.02	68	59
	21-12-12	8.63	92	32
Jamuna D/S	26-04-12	9.57	373	6

Sample location	Date	Depth (m)	Actual sediment concentration (mg/l)	Predicted sediment concentration (mg/l)
Right Channel LB (Ref. Figure 5.12)	05-06-12	6.49	142	92
	05-06-12	8.50	260	488
	16-06-12	10.69	442	609
	16-06-12	11.44	340	527
	20-06-12	9.62	599	265
	20-06-12	10.06	667	1156
	27-06-12	6.80	636	1554
	27-06-12	5.00	575	2573
	09-07-12	7.00	518	2276
	09-07-12	10.00	456	1159
	17-07-12	11.59	1114	470
	24-07-12	14.58	398	364
	30-07-12	12.90	294	33
	12-09-12	4.00	357	108
	27-09-12	13.20	1455	477
	09-10-12	4.00	578	634
	21-10-12	3.26	433	174
Jamuna D/S Left Channel RB (Ref. Figure 5.12)	05-06-12	7.30	136	568
	16-06-12	4.50	647	942
	20-06-12	8.00	613	441
	28-06-12	7.50	735	1675
	28-06-12	9.30	974	894
	09-07-12	8.54	550	711
	17-07-12	8.77	951	1712
	24-07-12	12.50	1076	1264
	30-07-12	8.00	679	96
	12-09-12	14.00	362	205
	27-09-12	16.00	816	225
	09-10-12	15.20	242	268
	21-10-12	14.71	474	134
	21-12-12	4.62	19	15
Jamuna D/S Left Channel LB (Ref. Figure 5.12)	26-04-12	11.36	728	419
	05-06-12	11.60	343	383
	05-06-12	9.00	164	192
	16-06-12	9.53	256	146
	20-06-12	13.80	302	578
	28-06-12	5.90	1141	341
	09-07-12	10.12	661	842
	17-07-12	4.86	1552	465
	24-07-12	8.51	519	1976
	30-07-12	8.00	907	620
	12-09-12	3.40	498	0
	27-09-12	3.20	1704	973

Sample location	Date	Depth (m)	Actual sediment concentration (mg/l)	Predicted sediment concentration (mg/l)
	09-10-12	4.60	1041	696
	21-10-12	7.35	675	98
	21-11-12	8.40	44	5
	21-12-12	7.94	40	12

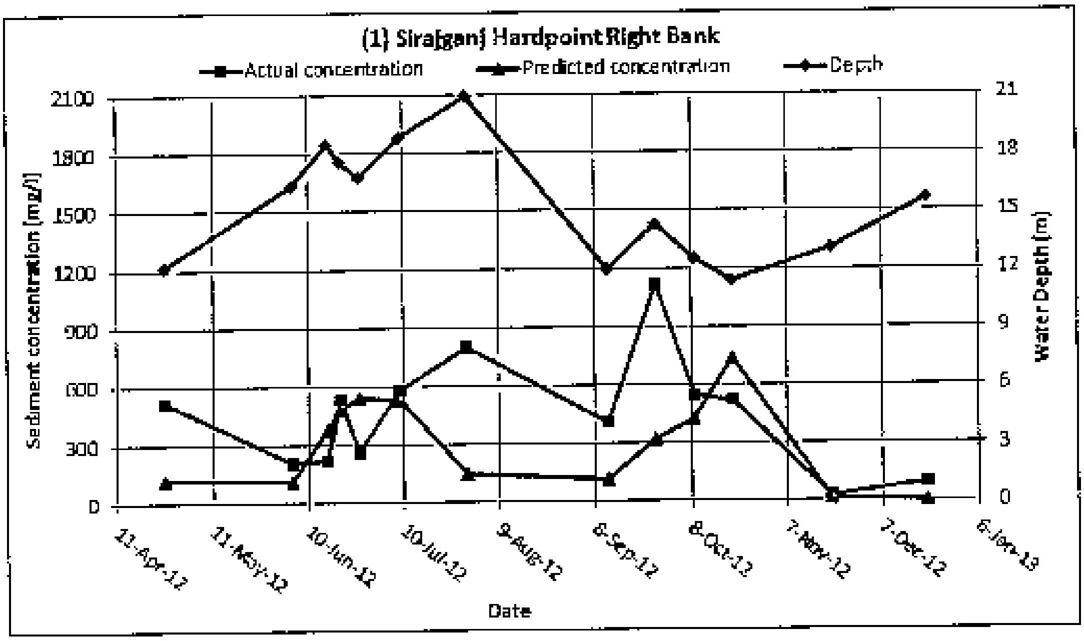
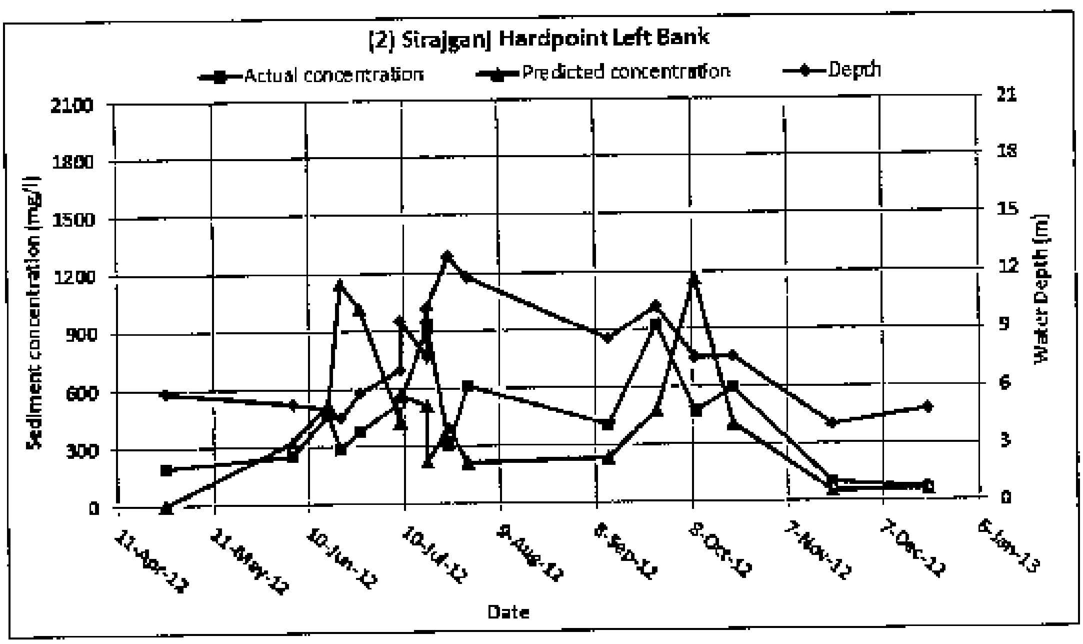


Figure 5.22: Depth, predicted and actual sediment concentration at Sirajganj Hardpoint Right Bank of Jamuna River in period April, 2012 to January, 2013.



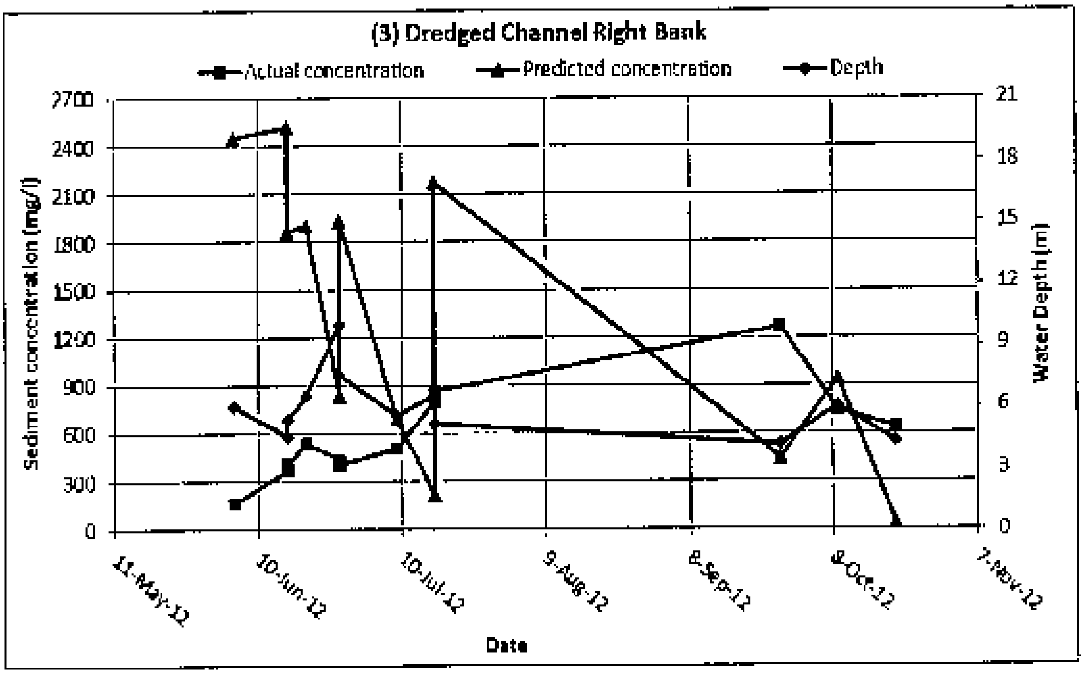


Figure 5.24: Depth, predicted and actual sediment concentration at dredged channel right bank of Jamuna River in period May to November, 2012.

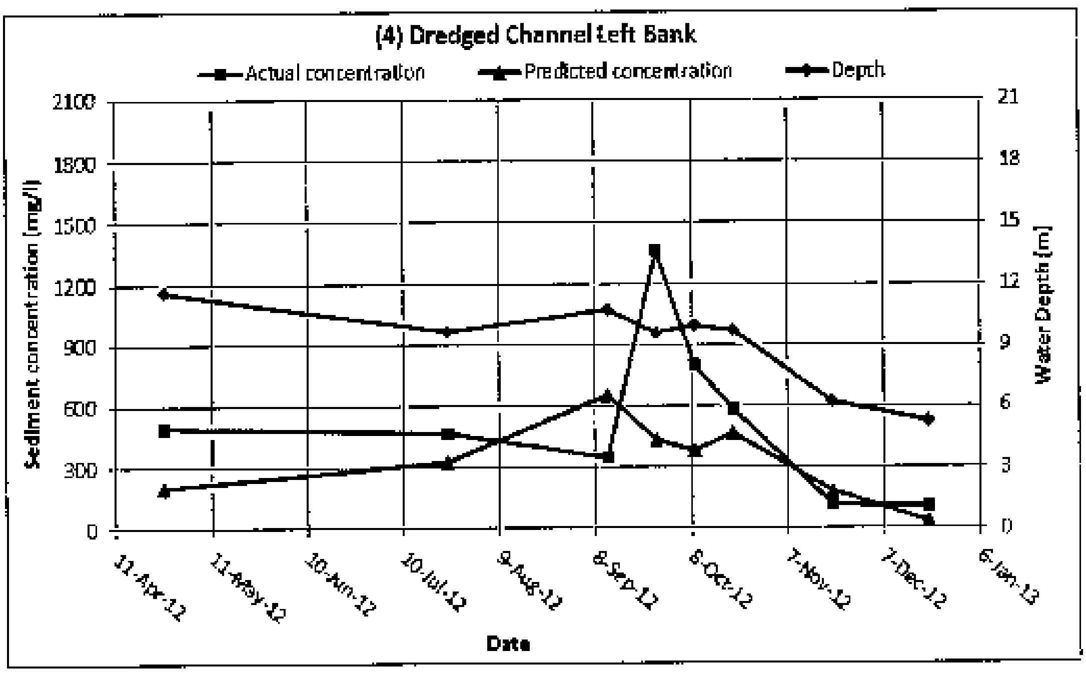


Figure 5.25: Depth, predicted and actual sediment concentration at dredged channel left bank of Jamuna River in period April, 2012 to January, 2013.

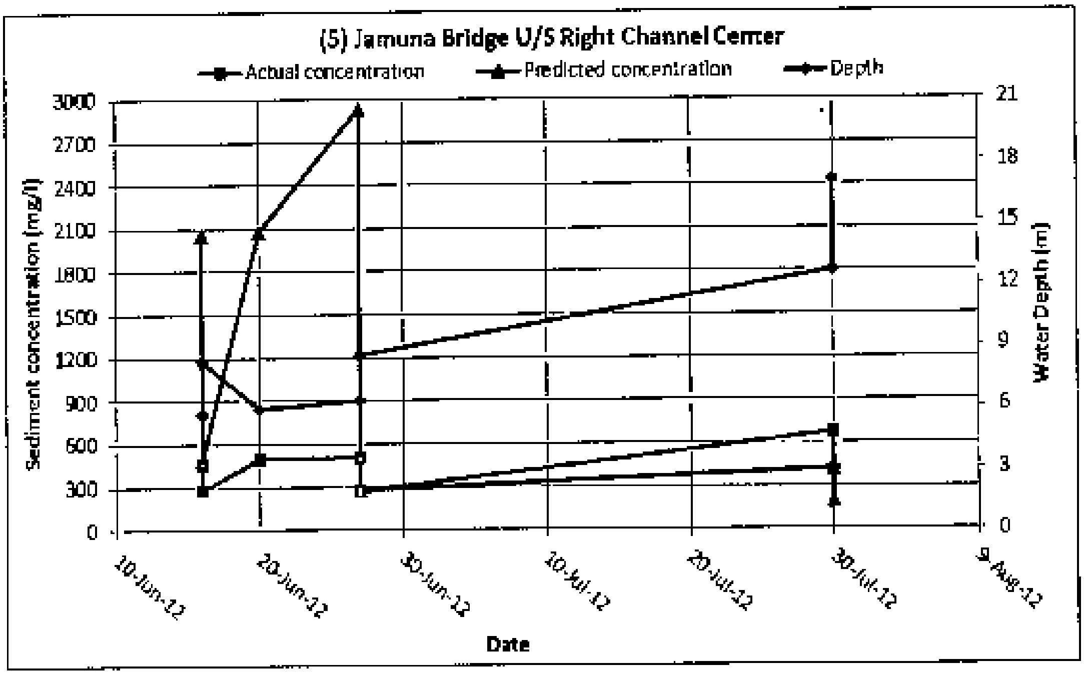


Figure 5.26: Depth, predicted and actual sediment concentration at Hangabandhu Bridge U/S right channel center of Jamuna River in period June-August, 2012.

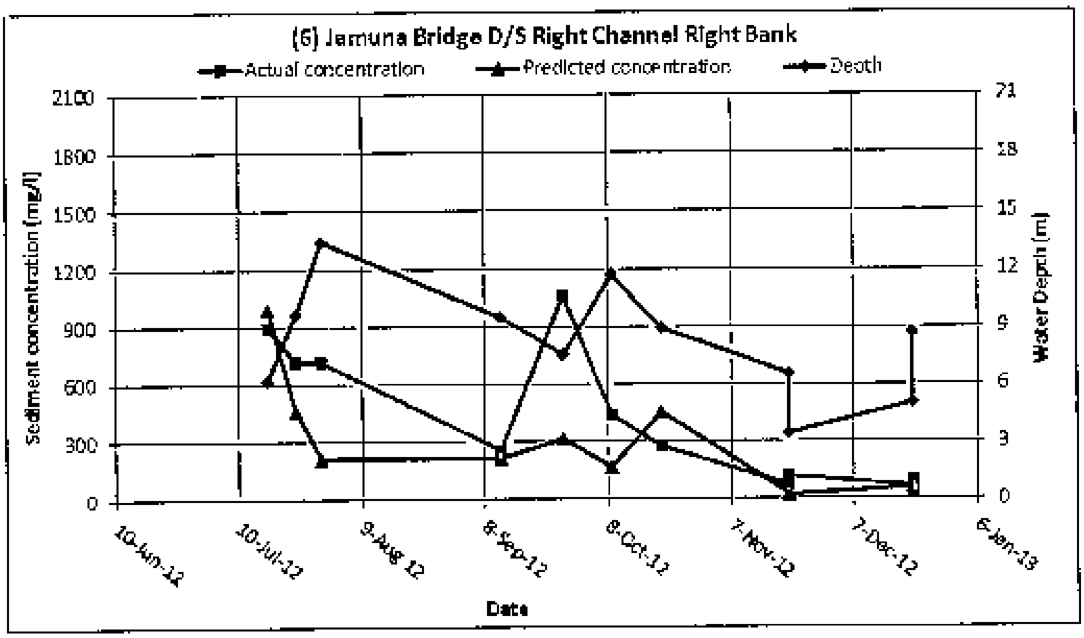


Figure 5.27: Depth, predicted and actual sediment concentration at Bangabandhu Bridge D/S right channel right bank of Jamuna River in period June, 2012 to January, 2013.

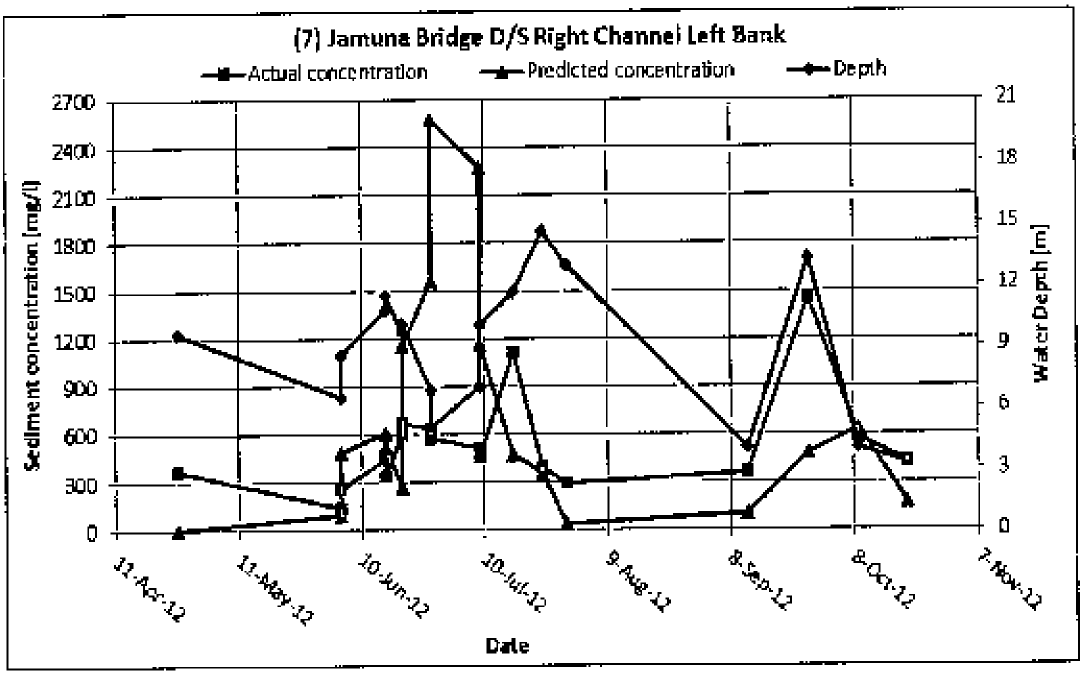


Figure 5.28: Depth, predicted and actual sediment concentration at Bangabandhu Bridge D/S right channel left bank of Jamuna River in period April-November, 2012.

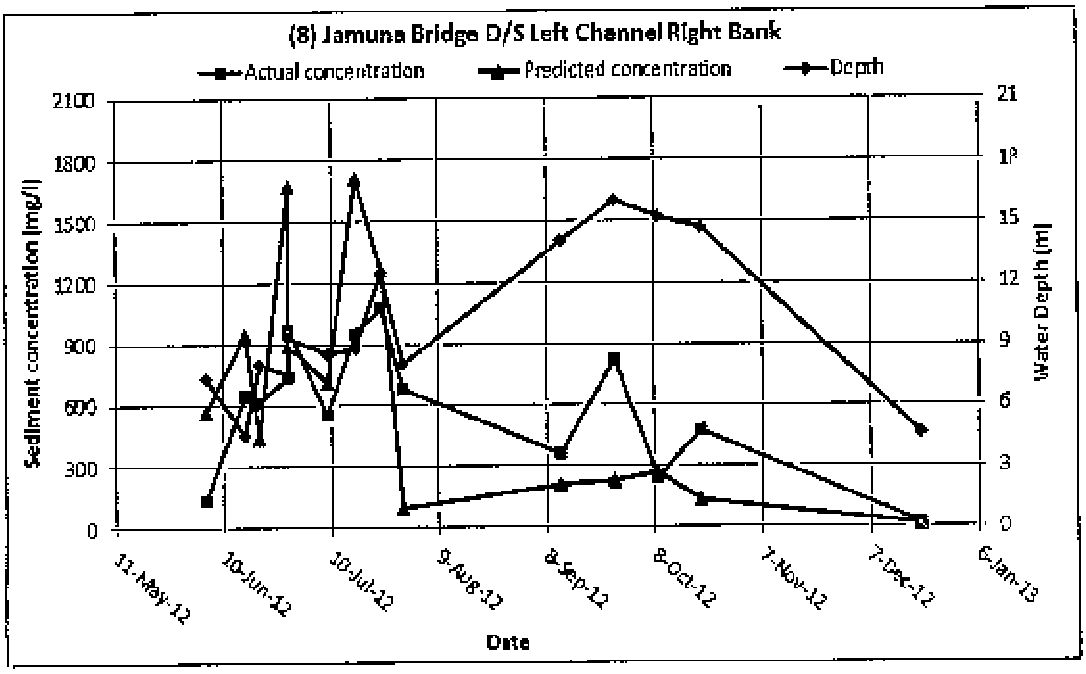


Figure 5.29: Depth, predicted and actual sediment concentration at Bangabandhu Bridge D/S left channel right bank of Jamuna River in period May, 2012 to January, 2013.

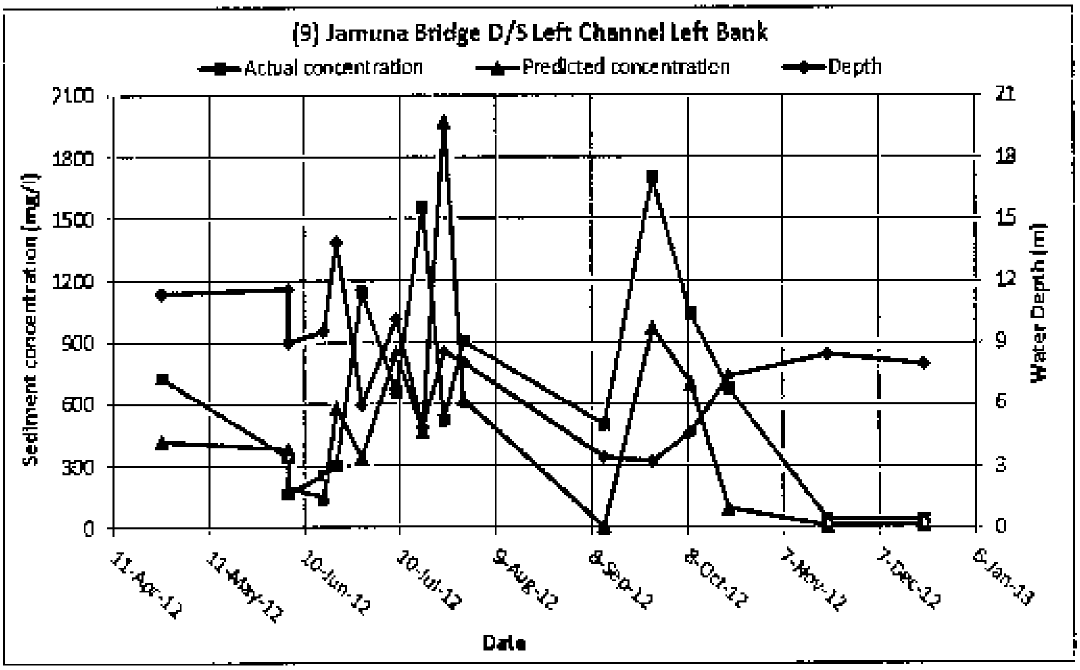


Figure 5.30: Depth, predicted and actual sediment concentration at Bangabandhu Bridge D/S left channel left bank of Jamuna River in period April, 2012 to January, 2013.

Observation from Method-II (Depth-velocity & sediment concentration relationship) represented by:

- Figure 5.22 and Figure 5.23 shows that the depth of water and sedimentation concentration on Sirajganj Hardpoint right bank and left bank of Jamuna River. Both of the figures represents that the rate of actual sediment concentration is higher than the predicted sediment concentration during the analyzing period. But in the month of June-July and October-November, 2012, the rate of predicted sediment concentration is higher than the actual sediment concentration. This scenario has been compared with the measured cross-section shown in Figure 5.7. It indicates that, the sedimentation occurs round the year at both bank, but during rising and falling water level condition river bed or bank erosion may happen.
- Figure 5.24 shows, the rate of actual sediment concentration is higher than the predicted sediment concentration and Figure 5.25 shows, the actual sediment concentration is higher than the predicted sediment concentration on dredged channel right bank and left bank of Jamuna River. In this location the dredging alignment passing through the high char. It was happing due to loose soil material at the char, when flow was passing through the dredged channel. The right bank of the dredged

channel was eroded due high flow velocity and left bank was silted up due to slope failure of the bank. Due to this condition the size of the dredged channel was widening but the depth of the channel were decreased which is compared with the measured cross section shown in Figure 5.8.

- Figure 5.26 shows; the rate of actual sediment concentration is higher than the predicted sediment concentration on Bangabandhu Bridge U/S (center of the right channel) in the period of June, 2012. Because the maximum flow were passing through the channel in monsoon. It indicates that the channel was eroded in the monsoon and in the dry and pre-monsoon and post-monsoon the channel was silted up at that location, which is compared with the measured cross-section representing in Figure 5.10.
- At the downstream of Bangabandhu Bridge the major flow passing through the left channel. During monsoon it is quite difficult to divide it as left or right channel. Figure 5.27 and Figure 5.28 shows that most of the time the rate of actual sediment concentration is higher than the predicted sediment concentration on Bangabandhu Bridge D/S right channel both right and left bank. But in Figure 5.28 represents the predicted sediment concentration is higher in the period of June, 2012. Both of the figures indicate that both bank of the right channel were silted up round the year. They also indicate that the left bank of the right channel may erode only in monsoon, this scenarios is compared with the measured cross-section represented in Figure 5.11.
- Figure 5.29 and Figure 5.30 shows that most of the time the rate of actual sediment concentration is higher than the predicted sediment concentration on Bangabandhu Bridge D/S left channel right and left bank, except in the monsoon. Both of the figures indicate that both bank of the left channel were silted up round the year. They also indicate that the both bank of the left channel may erode only in monsoon, this scenarios is compared with the measured cross-section represented in Figure 5.11.

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Summary results from sediment concentration and depth average velocity analysis:

The morphological change of the sand-bed braided river like the Jamuna River is a great challenge for the structural stability of river training works. This study investigates the unsteady pattern of river flow as well as variations of river bed elevation and sediment transport due to the period of 2012. It can be observed that most of the overloading area is deposited in the period of dry season, 2012. In most of the figure are only shown the observed suspended sediment concentration which is higher than the predicted concentrations. In natural rivers there are always some uncertainties in estimating the relevant parameters due to their variation in space. It is observed that the flow in the Jamuna River, especially during the high flow is not in equilibrium with the riverbed topography, but rather is governed by upstream conditions and the momentum of the flow. The results from data analysis are summarized in Table 5.5:

Table 5.5: Erosion and deposition matrix at nine locations around the study area using Method-I and Method-II

Sample location	Date of observation	Method-I			Method-II			Remarks from field observation
		Erosion (%)	Deposition (%)	No erosion/ deposition	Erosion (%)	Deposition (%)	No erosion/ deposition	
Sirajganj Hardpoint RB	April, 2012 to January, 2013	7	79	14	20	60	20	Deposition
Sirajganj Hardpoint LB	April, 2012 to January, 2013	56	26	18	16	56	28	Deposition
Dredged channel RB	May to November, 2012	84	0	16	69	23	8	Erosion
Dredged channel LB	April, 2012 to January, 2013	23	15	62	8	75	17	Erosion
Bangabandhu Bridge U/S right channel Center	June-August, 2012	58	14	28	44	14	42	Erosion
Bangabandhu Bridge D/S right channel RB	June, 2012 to January, 2013	10	45	45	9	55	36	Deposition
Bangabandhu Bridge D/S right channel LB	April-November, 2012	48	26	26	40	35	25	Erosion
Bangabandhu Bridge D/S left channel RB	May, 2012 to January, 2013	57	43	0	25	63	12	Erosion
Bangabandhu Bridge D/S left channel LB	April, 2012 to January, 2013	44	38	18	19	56	25	Deposition

From the above Table 5.5 out of 9 sites, the observation and prediction of erosion or deposition are matching well at 7 sites, while two sites (Dredged channel LB and Bangabandhu Bridge D/S right channel LB) are not matching. It happens, because local hydro morphological parameters (depth, velocity and sediment concentration etc.) are very influenced by the upstream morph-dynamic processes (sandbar formation, translation). Further. the equations used in the above analysis are one dimensional in nature, while the local morpho-dynamic processes that is very much dependent on the upstream morphology is three dimensional in nature (Uddin, 2010). To explain the above issues with confidence further three dimensional analysis is required.

CHAPTER SIX
CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

River channels tend to a dynamic equilibrium driven by the dynamics of discharge of water and sediment transport. Different river training works, upstream interventions increasingly change the natural drivers of the channel morphology. The major findings of this study are:

- Due to translation of sandbars along downstream, flow were diverted towards the bank and caused bank erosion. The channel is developing very fast along the western bank of the Jamuna River and erode the river bank.
- Satellite image analysis indicates that the flow processes and the location of active bank erosion changes significantly due to changes in large scale sand bar movement (both laterally and longitudinally).
- Cross-section comparison indicates that the channel near Sirajganj Hardpoint shift towards East. The existing channel near Sirajganj Hardpoint is silted up within very few days after dredging. It is also observed that after 1 year of monsoon flooding the impact of dredging is very minor around the study area
- Analysis of observed data indicates that, during May-September, 2012 the depth average velocity near the Sirajganj Hardpoint area exceeds 1.75 m/s and consequently during the above period sedimention did not occur.
- There is no significant impact of dredging has observed near Hardpoint as well as the downstream of Banghabhandhu Bridge. It is also observed that the rate of siltation is higher, where the dredging alignment passing through the existing char. It was happening, because we cannot change the hydraulic condition around the dredged area as well as upstream river morphology. It seems that the dredge channel may silt up within a very short period.
- From the analysis of sediment concentration and depth average velocity, it is observed that sediment concentration plays an important role in the erosion or deposition processes from upstream of Sirajganj Hardpoint to downstream of Jamuna Bridge near Dhaleswari Offtake.

- The major finding of this study is that the dredging of a braided river would not be a sustainable solution without changing upstream river morphology as well as hydraulic conditions. It is also observed that, if the dredging alignment passes through the existing channel not over the char area, the dredged channel would be more sustainable.
- In this study, one dimensional morphological equations has been used to predict erosion/deposition process. In natural rivers there are always some uncertainties in estimating the relevant parameters due to their variation in space/time using one dimentional equations. Three dimensional analysis may provide better understanding on the above issues.

6.2 Recommendations

The rivers of Bangladesh facing large flow fluctuations between the high water period in the June-October period and low water period during the rest of the year. The analysis of this study has been done for a very short period. It is recommended that further study is needed considering:

- The flow pattern changes with changing flow regime which may vary from location to location. Therefore, long term monitoring on the behavior of the erosion and sedimentation processes at the study bend need to be explored for future development
- Bar dynamics are related to the morphologic behavior as bank erosion and flow processes of the rivers. To understand the dynamics of the upstream river morphology such as movement of large scale sand bars, a time series satellite image based analysis is essential.
- To assess the morphological behavior of a river, two dimentional morphological model is mendatory. It is also suggested that, in comprehensive river management plan, further research is required for future dredging requirement of the country.

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