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Research Article

IDENTIFICATION OF EROSION SUSCEPTIBLE RIVER BANK SITES OF KALINDRI RIVER, MALDA DISTRICT, WEST BENGAL

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ABSTRACT
Kalindri River in Malda district, West Bengal displays varying degree of erosion. The Kalindri is the branch of River Phulhar experienced severe channel change due to lateral shifting associated with bank erosion over course of time. River bank erosion is a natural process and severe bank erosion has serious consequences for physical and biological processes of environment. In some villages around the Kalindri River bank erosion creates serious problem for the people living their destroying their crops. To predict the bank erosion the multi metric tool Bank Erosion Hazard Index is calculated. BEHI takes into consideration several aspect of bank condition and provides an overall score that can be used to predict the bank erosion over a large area. This paper mainly focuses on identification of potential river bank erosion risk sites along river Kalindri using some other scores like stability scores and ribbon testing, Erosion rate. After constructing models using those methods it is also tried to validate all of these in reference to each other in the one hand and with actual river bank erosion and bank recession data measured directly from the field in last three years on the other hand.

Keywords: *Kalindri River, Bank Erosion, Bank Erosion Hazard Index, Stability Index Assessment Scores, Ribbon Test, Erosion Rate, Validation of Scores*

INTRODUCTION
Among the various types of hazards, including cyclone generated coastal floods, river floods, tropical cyclone and drought, the socio-economic impact of reverie hazards in West Bengal is more extensive and devastating relative to other types of hazards. The Kalindri River in Malda district of West Bengal is a connective river between river Phulhar and Mahananda has long been considered as a dynamic river due to frequent changes in its course (Das and Pal, 2016). A number of paleo channels and ox- bow lakes of Kalindri suggest the migratory nature of the river. River bank erosion is therefore, an important feature of river Kalindri and during rainy season it takes horrible situation in some reaches. Bank erosion is a natural phenomenon governed by many factors which include flow regime, geological structure and stability, lithological characteristics, land cover, soil properties and anthropogenic activities (Stott, 1997; Wischmeier and Smith, 1978; King and Le Bissonnais, 1992; Gouée *et al.*, 2010; Baishya, 2013). The factors controlling stream bank erosion have attracted attention from geomorphologists, hydrologists and river engineers for several decades (Stott, 1997). River bank erosion in particular, is affected by the excavation of soil for brick making and building materials, cutting trees, cropping pattern management and dumping of the solid materials mostly close to urban centre (Ahmed *et al.*, 2010). Deforestation and agricultural land use patterns have been shown to influence stream bank erosion and channel instability (Lyell, 1830; Simon, 1989; Rosgen, 2001; Shields *et al.*, 2010). Alluvial courses are very sensitive indicators for channel change and can re adjust to variation in hydrology, sediment load and active tectonics (Schumm *et al.*, 2000). Eroding stream banks can be a major source of sediment to a stream (Simon and Thorne, 1996). Riverbank erosion, associated sedimentation and land loss hazards are a serious resource management problem of global significance (Darby and Thorne, 1994; Odgard, 1987). The significance of stream bank erosion processes that contribute sediment to the total annual sediment transport has often been overlooked or misunderstood as most of studies on sediment supply have been directed to surface erosion processes, which in many disturbed landscapes are the major sediment sources (Rosgen, 2001). The adverse consequence of increased stream bank erosion results not only in accelerated sediment yields, but also to changes in stream channel instability and associated stream type changes

(Rosgen, 2001). Bank erosion may also occur when a streams shift laterally along the dip of the rocks leading to concentrated erosion on one of the channel banks (Baishya, 2013). Sinuous alluvial river channel inherently migrates, creating conflicts between bank erosion and human activities near riverbanks (Larsen and Greco, 2002). Migrating streams tend to erode the banks and widen the channels by undercutting and bank caving the eroded material is then washed away by the flow.

River bank erosion has a long-term consequence on human life (Das, 2010; Das *et al.*, 2014). The extensive bank erosion has led to numerous social and economic consequences – loss of agricultural land (loss of livelihood), loss of housing and other essential infrastructure, displacement and involuntary migration promoting native-migrant contest over limited resources, ethnic tensions, distrust and political instability and civil strife in the basin (Reuveny, 2007). Many of those erosion-distressed people loose not only their homes, means of livelihood and assets but also their previous identity, and they, therefore, often try hard for recognition of an identity (Das, 2010). River bank erosion is permanent and has a long term impact on the economy. Once residential and productive land is lost due to river bank erosion, it can hardly be replaced (Das *et al.*, 2014).

One of the important tools for prediction of bank erosion is Bank Erosion Hazard Index (BEHI). BEHI is a semi-quantitative multi-metric index for estimating bank erosion potential in streams and is comprised of estimates and/or direct measurements of the ratio of bank height/bank full discharge height (i.e., maximum height of water at bank full discharge), the ratio of rooting depth/bank height, root density, bank angle, and the percent of surface protected by vegetation (Rosgen, 2001). This paper mainly focuses on identification of potential river bank erosion risk sites along river Kalindri using some of the scores like BEHI, stability scores and ribbon testing. After constructing models using these methods it is also tried to validate all these in reference to each other in the one hand and with actual river bank erosion and bank recession data measured directly from the field in last three years on the other hand. Based on the results of validation it is planned to establish these models on any one of these models to be represented as the most suitable for future work in this field.

Study Area

The Course of river Kalindri and associated old courses has been selected as study area for this paper. This river has historically experienced a long course of evolution. According to Sengupta (1969), Kalindri river is known as a distributary of the eastern branch of the river Ganga. According to Sengupta (1969) and Lambron (1918), Phular was a branch of river Mahananda and lower part of this river was considered as Kalindri. Carter (1935) in his settlement report has described the course of river Kalindri in the District of Malda as it is existed in 1935: “The Kalindri has always been connected with the Ganges by navigable Channel, down which the flood water of Ganges passes”. According to filed visit the river Kalindri a branch of River Phulher which is bifurcated from Phulher at Najirpur ($87^0 53^{'} 48^{''}$E and $25^0 08^{'} 13$") in Malda district (See Figure 1). It is flowing mainly south east and join Mahananda River at Nimasari Ghat ($88^0 8^{'} 07^{''}$ E and $25^0 02^{'} 42^{''}$ N). The northern portion of this river has been known as ‘Tal’ land and the southern portion called ‘Diara’. Diara region is the most fertile and the most populous area of the district (Das and Pal, 2016). This river basin is also known for its glorious history, a reference is found in the Ramacharita by Sandhyakara Nandi of the River Kalindri in which it has been stated that Madanapala defeated his enemy on the bank of the Kalindri river (Sengupta, 1969). According to the GSI report the maximum portion of study area composed by Entisol (This is a very diverse group of soils with one thing in common, little profile development) and Inceptisol. Both of the soil is made of by alternative deposit of sand, silt and clay. Diara region composed with new alluvium where as the Barind region composed by old alluvium. According to G.S.I report 2008 the entire area divided within four distinct regions, these are 1) Upland, 2) Active flood plain, 3) Inactive flood plain and 4) Restricted flood plain. The upland which is found in the eastern portion of the study area is basically formed by Older Alluvium of Pleistocene age (Das and Pal, 2015). The maximum portion of the region is a part of active flood plain which is formed by immature, loosely compacted newer alluvium with higher moisture content (Ckakraborty *et al.*, 2007). According to geological map (see figure-4) there are several fault line within study area and the Kalindri situated within a triangle formed by several fault line which make region very erosion and migratioprone.

According to Purkait (2008) ground water flow is very slow in the study region as the hydraulic gradient is very low and there are so many of cut-off channels, meander belts and ox-bow lakes which showing the evidences of previous channel change of various rivers.

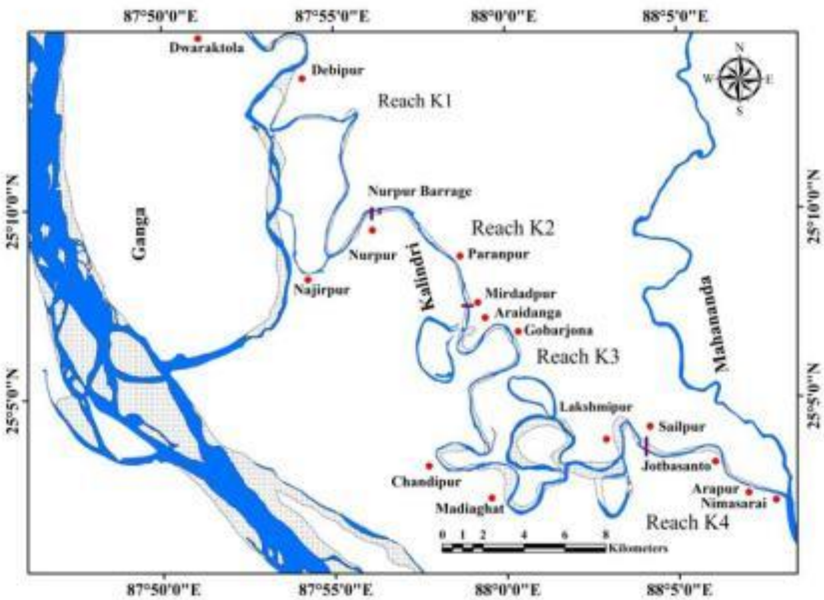

Figure 1: The Course of River Kalindri, 1974
Source: Topo-Sheet, Survey of India

For field measurement 11 sites have been selected for the study. The sites are Najirpur, Paranpur, Mirdadpur, Araidanga, Gobarjona, Lakshmipur, Chandipur, Madiaghat, Sailpur, Jotbasanto, Arapur and Nimasaraighat. Amon them Najirpur situated in Upper reach of kalindri (in K1), Nurpur and Paranpur and Mirdadpur situated at K2 reach. Araidanga, Gobarjona, Lakshmipur, Chandipur, Madiaghat situated at K3 reach of Kalindri whereas Sailpur, Jotbasanto, Ararpur and Nimasaraighat situated in K4 reach of river Kalindri. The Kalindri River, a distributary of river Phulhar, exhibits a complex fabric of channel change over time (Das and Pal, 2015). Frequent migration of river has created a good number of wetlands and these have generated a good economic prospects and livelihood supports (Pal and Kar, 2012). Agricultural land is engulfed but such migration and new fertile land is also emerged which can support advantages to the farmers According to field study occurrence of flood in this region is a common phenomena and water logging in rainy season also happened in this region. Eastern portion of this region characterized by gully and rill activities.

Figure 2: Erosion, Left Bank, 70m Upstream Madia Ghat, 2015

Figure 3: Erosion, Right Bank, 100m Upstream from Nimasarai Ghat, 2015

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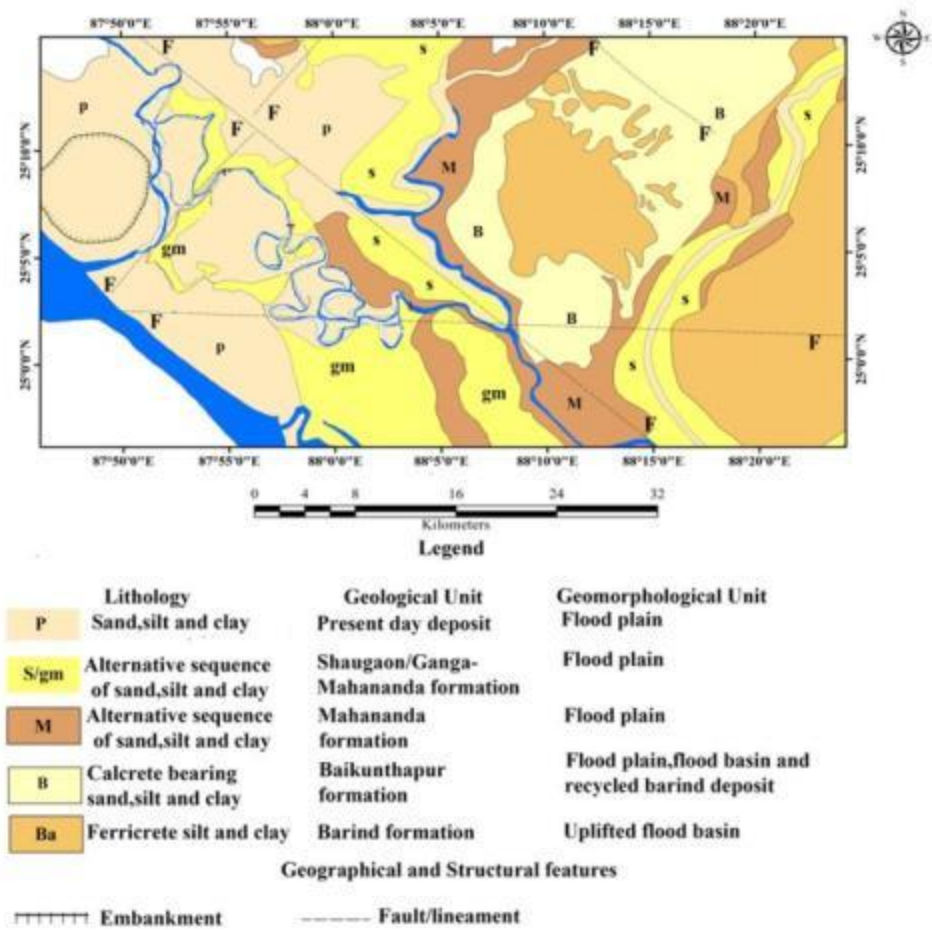

Figure 4: Geotechnical Characteristics and Natural Hazard Map, 1995
Source: GSI Report, 1995

MATERIALS AND METHODS

Materials

A detail empirical survey has been conducted in different parts of course of Kalindri River and associated old courses for measuring of depth, width, velocity (where applicable), suspended and dissolved load, bank material, bed material, Ratio of bank height to bank full height, root depth, bank angle, surface protection etc. From entire present river course, 11 sites have been surveyed as shown in figure 1. Toposheets of Survey of India (1924, 1971-72), Land sat 5 images (2005), google image (2015), cadastral map of Revenue survey, Government of West Bengal (1951) and Natural hazard map (1995), Quarternary Geology and Geomorphology map of North Bengal, GSI report 2008 have been used to draw a general concept about this region.

Methods

Data Collection Method

Primary data has been collected directly from field. Eleven sites have been selected for survey. Selection of the sites has been done on the parameters such as erosion, deposition and stability, scour formation etc. Dumpy and Abney's level survey has been used to measurement of depth, width etc. Soil and Water sample have been collected for measuring the texture of soil, suspended sediment load, and dissolved sediment load and water. Bank material has examined following the ribbon test method. Latitude, longitude and altitudinal data are also collected through the help of GPS.

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Data Analysis Methods

Method for prepare Bank Erosion Hazard Index

Bank Erosion Hazard has been measured in this paper following Bank Erosion Hazard Index (BEHI), framed by Rosgen (2001). The complete BEHI procedure consists of five metrics; one requiring some measurements and other four based on some observation. They are: 1) Ratio of bank height to bank full height, 2) Ratio of root depth to bank height, 3) Root density (%), 4) Surface protection (%) and 5) Bank angle (degree). After collection of all data individual scores of each dimension has been calculated and finally overall scores for the complete BEHI are calculated by summing the scores for each individual metric using the values.

Figure 5: Ribbon Test in Left Bank of Kalindri in Nimasarai, September, 2014

Assessment of cohesiveness of bank material

A more semi quantitative assessment of bank material cohesiveness is ribbon test. At first a ball of soil with equal volume was taken in the palms of hand and it was rolled into a cigar shape by pushing the soil out between the thumb and fore finger. Then it was squeezed upward into a ribbon. The ribbon was made of uniform thickness and width. Finally the ribbon was allowed to emerge and extend over the forefinger and it will help to break the ribbon from its own weight.

Method for Channel Stability Assessment

According to Rosgen (1996), Stream channel stability is the ability of a stream, over time, in the present climate, to transport the sediment and flows produced by its watershed in such a manner that the stream maintains its dimension, pattern and profile without neither aggrading nor degrading. Several number of methods currently are available for assessing channel stability. Majority of these methods are based on observations of a variety of parameters that describe the characteristics and conditions of the channel and surrounding flood plain.

Pfankuch (1975) created a relative channel stability ranking for the U.S. Forest Service in the central and western US states, which Rosgen modified to consider channel types. Systematic data collection is an integral part of assessing channel stability. The amount of data that is required depends on the level of detail desired.

To measure the stability of a stream channel the most common measure is the Channel Stability Assessment Scheme (CSAS), in which twenty parameters are used to make an assessment on stability of a stream channel.

These are primary bed material, bank material, degree of incision, degree of channel bed accretion or degradation, stature of channel bed accretion or degradation, top bottom width ratio, width depth ratio, degree of constriction, stage of channel evolution, sinuosity index, vegetative rooting depth in bank, vegetative rooting density in bank, established riparian woody vegetative cover, occurrence of bank accretion, stream bank instability (% of each bank failing), stream bank recession or aggression, stream bank erosion, active stream bed/bar deposition, stream bed exposure and wetted width and dry width ratio.

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Techniques of Measuring River Bank Recession

At eleven sites where BEHI score is measured, toe pin have been used for successive three years (2013-2015). Each year it is measured that how much the bank is recessed from their previous position.

Methods for Data Validation

One of the integral features of the paper is checking validity of BEHI scores. For validation average BEHI scores, stability index scores, length of ribbon and bank erosion rate were taken. Validation of BEHI scores have been trying to determine through the method of correlation matrix using the above mentioned scores and bank erosion rate. It is considered that (1) if bank recession rate is high where BEHI score is also high (2) if bank recession rate is low where channel stability score is high (3) if bank recession rate is low where length of ribbon is more (4) if BEHI score is negatively and significantly correlated with stability and ribbon length in respective sites these semi quantitative models for measuring river bank erosion will be valid.

RESULTS AND DISCUSSION

BEHI (Bank Erosion Hazard Index) was calculated to provide bank erosion estimates. BEHI evaluates properties of stream banks related to stability. Figure 6 shows the average bank erosion hazard index map. Of the 11 sampled sites, there are considerable variation in BEHI variables and final index scores. BEHI scores for left and right bank separately as well as average BEHI scores for each site also has been calculated. According average BEHI scores for both bank one site is ultimately classified as very high hazard, four sites are high hazard and six classified moderate. Figure 5 displays BEHI for left bank and right bank separately. According to figure 7 left bank of river Kalindri at Najirpur Hahajan ghat classified as extreme erosion hazard prone as the value is recorded more high than other. Right bank of displays very high score of BEHI which indicate unstable situation of right bank. Left bank of Kalindri at Chanipur, Madiaghat and Nimasarighat classified as moderately erosion prone as the total index score recorded between 14.76 to 24.75.Right bank of madia ghat classified as low erosion prone (see Figure-5).

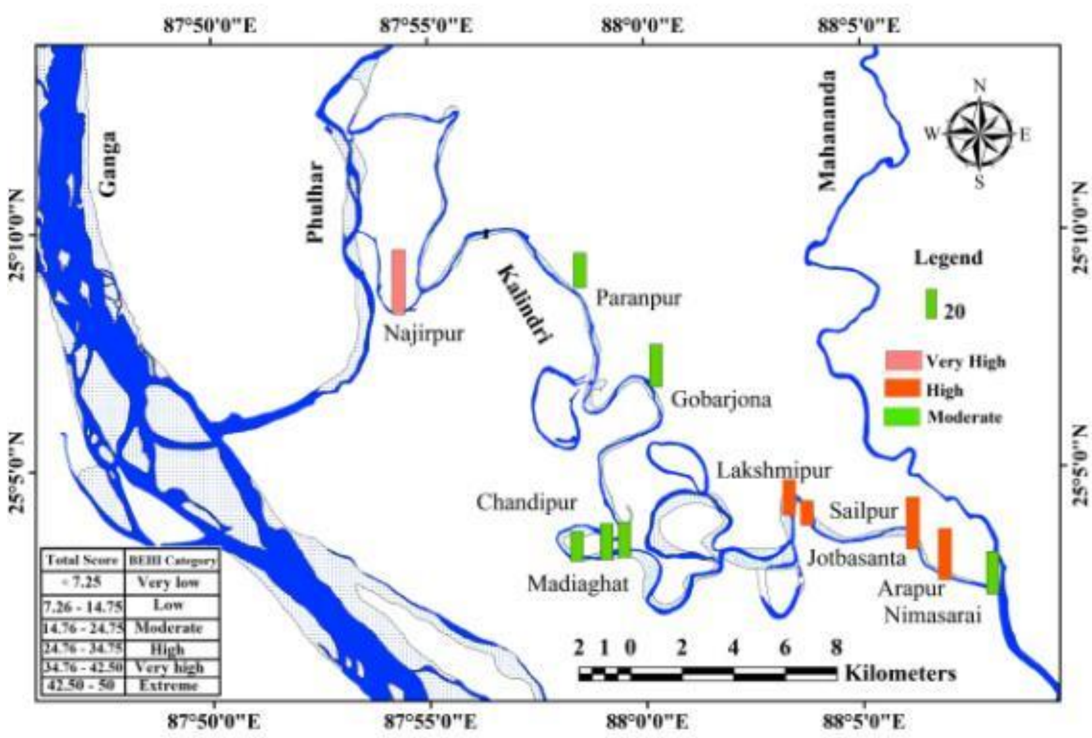

Figure 6: BEHI Map, 2015

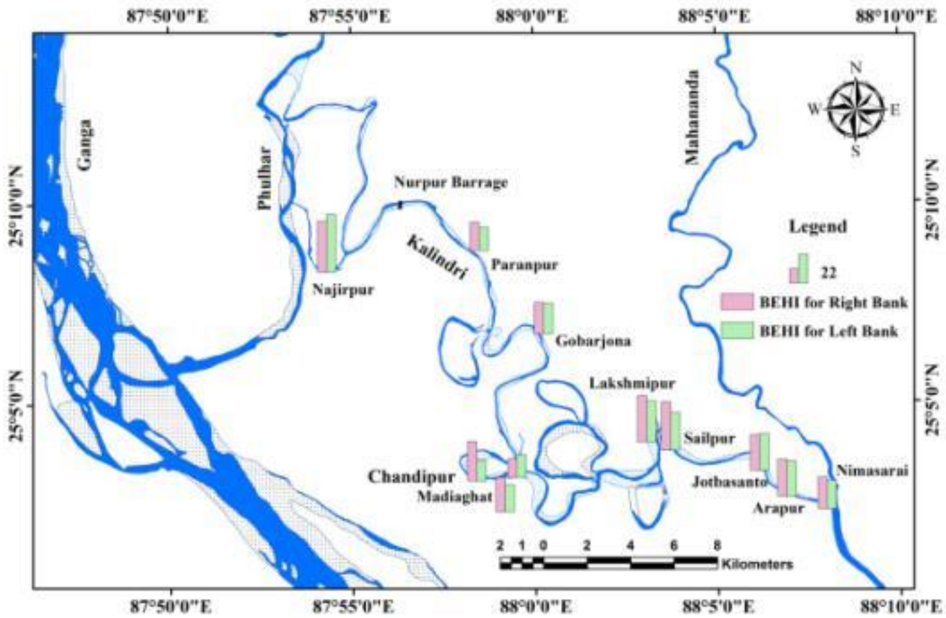

Figure 7: BEHI Map

Figure 8: Bank Erosion, Right Bank of Kalindri, Najirpur, 2015

Figure 9: Bank Erosion, Left Bank of Kalindri, Lakshmipur, 2014

Figure 10: Bank Surface Cover, Left Bank of Kalindri, Sailpur, 2014

Figure 11: Bank Surface Cover, Left Bank of Kalindri, Sailpur, 2014

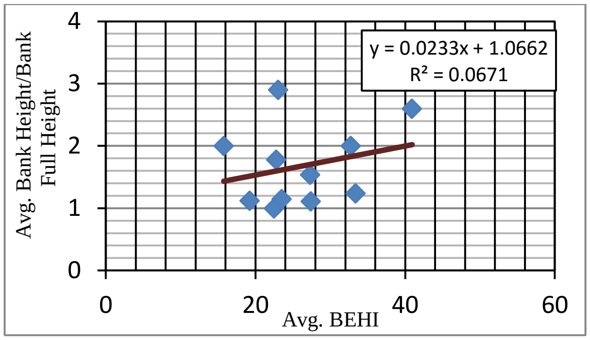

Figure 12: Relation between Bank Height/Bank Full Height and BEHI

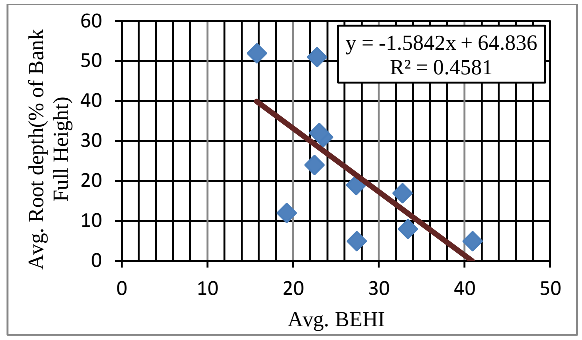

Figure 13: Relation between Root Depth and BEHI

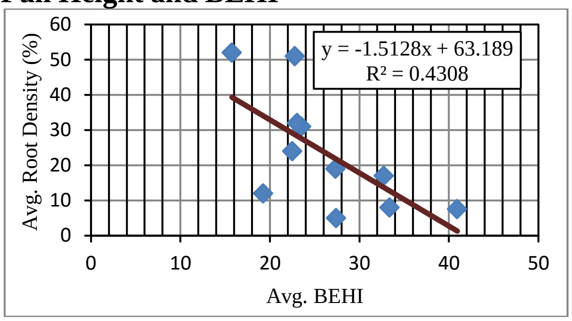

Figure 14: Relation between Root Density and BEHI

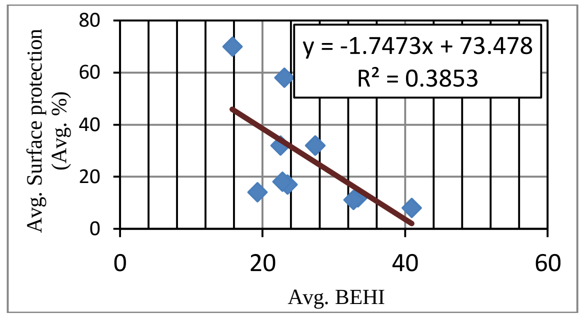

Figure 15: Relation between Surface Protection and BEHI

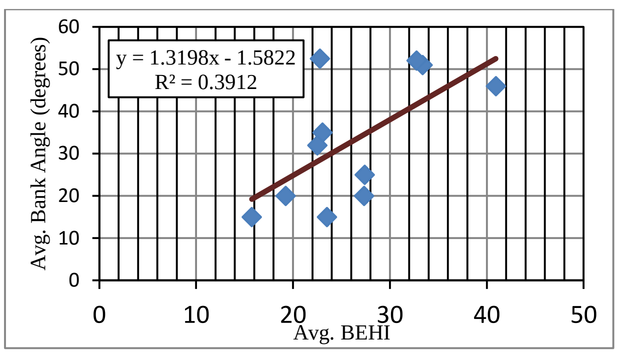

Figure 16: Relation between Bank Angle and BEHI

Figure 12 to 16 represents the relationship between various parameters and total BEHI scores. Theoretically there is a positive relationship between average bank height/bank full height and average BEHI scores. The figure 12 displays same thing as the bank height/ bank full height increases the BEHI scores also increases. The figure 13 to 15 represents inverse relationship between various parameters (average root depth, average root density, average surface protection) and BEHI. The root density at Chandipur in K3 site almost 51% and the average BEHI score is 22.78. But Najirpur situated in K1 reach showing quite different results where root density is recorded almost 7.5 % and the average BEHI score is 40.92. Presence of low vegetation root density and depth at Najirpur represents high potentiality of erosion.

One key component of the paper was to rank of potential sites for stream bank stabilization of the Kalindri River. Therefore, the scores for the Channel Stability Assessment Scheme were used to classify the stability of the banks. Figure 17 displays the stability condition of river Kalindri. CSAS scores suggested that 7 sites among the 11 sites were relatively stable (Figure 17). CSA scores for at least two sites among all the sites were highly stable these sites are Najirpur and 50 metre upstream of Madiaghat.

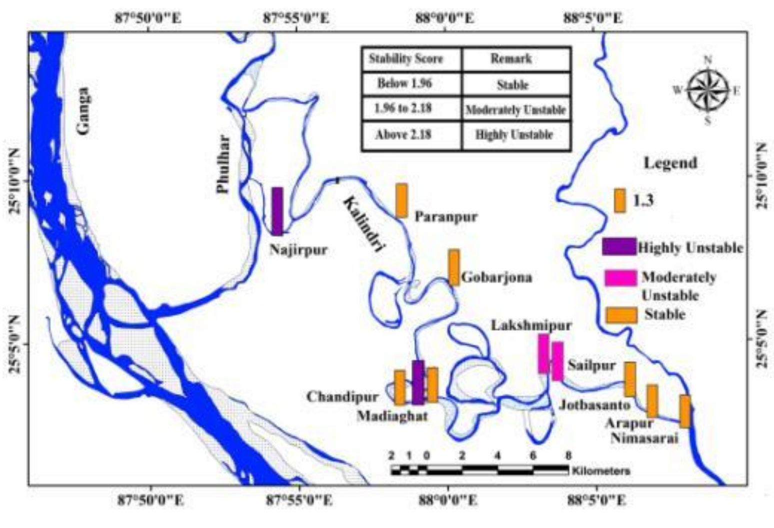

Figure 17: Stability Scores, 2015

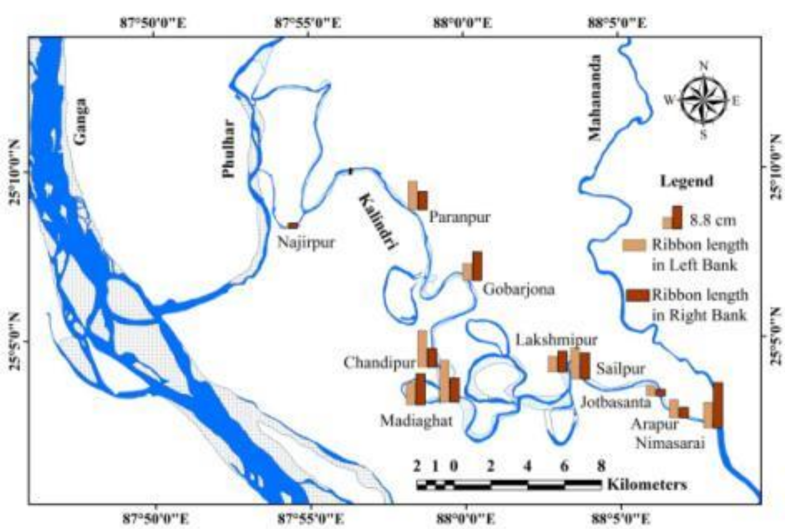

Figure 18: Ribbon Length, 2015

Figure 18 displays the thematic map based on ribbon length for both stream bank of Kalindri. The ribbon value for left bank in Najirpur is almost 0 (see table 1) which indicates the proportion of sand within soil is relatively high, therefore the erosion potentiality is also high. But situation is quite different in Nimasarai ghat where the ribbon length in right bank is 17.5 cm which indicates the proportion of clay within the soil of right is relatively high than other materials. The domination of clay in the soil of right bank in Nimasarai indicate the stable situation of right bank (see figure 18). According to ribbon test within K3 reach left bank of river kalindri at Chandipur, Madiagaht and Sailpur is relatively stable than right bank (see figure 18). At least one site (Lakshmipur) showing quite different result where potentiality of erosion is higher in left site than right. Table 1 also displays the average erosion rate for both left and right bank of the River Kalindri. Erosion rate for both the bank of Najirpur was relatively high as the rate of erosion recorded in left bank was 4.28 metre /year and in left bank was 3.2 metre/year. The erosion rate at the left bank of Chandipur and Sailpur were almost zero. Arapur showing quite different results as there is no evidence of erosion during last 3 years.

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Table 1: Summery of Various Scores within Different Sites

Site Id.	Site Name	BEHI (Left)	BEHI (Right)	Stability Score	Ribbon Length in cm (Left Bank)	Ribbon Length in cm (Right Bank)	Erosion Rate Metre/Year for Left Bank	Erosion Rate Metre/ Year for Right Bank	Average Erosion Metre/Year
1	Najirpur	43.45	38.4	2.52	0	2	4.28	3.2	3.74
2	Arapur	23.25	23.75	1.9	11	7	0.75	1	0.875
3	Gobarjona	21.25	17.25	1.78	6.5	13	0.25	0.78	0.515
4	Chandipur	15.75	29.8	1.86	8.75	12	0.57	0	0.285
5	50m Upstream of Madia Ghat	20.30	25.8	2.28	14.2	7.2	1.2	0.56	0.88
6	200m Downstream of Madia gaht	17.25	14.25	1.86	16.7	9.22	1.72	0.44	1.08
7	Lakshmipur	31.85	34.9	2.08	6	8	2.42	2.6	2.51
8	Sailpur	28.75	36.75	2	12	10	0.74	0	0.37
9	Jotbasanta	27.8	26.85	1.84	4	2.5	3.78	0.78	2.28
10	Arapur	26.95	27.85	1.74	7	4	0	0	0
11	Nimasarai	21.25	23.75	1.74	10	17.5	0	2.4	1.2

Source: Field Study, 2013, 2014, 2015 and 2016

The table 2 displays the validation of BEHI through co-relation matrix. There is a positive relationship between stability scores and BEHI scores. But there is a negative relationship between BEHI and ribbon length. Correlation between average ribbon length and BEHI is significant at the 0.014 level (2-tailed).

Table 2: Correlation among Various Scores (Value within Parenthesis Indicates Level of Significance)

	Average BEHI	Stability Score	Average Ribbon Length in cm	Average Erosion Rate (metre/year)
Average BEHI	1			
Stability Score	0.66 (0.027)	1		
Average Ribbon Length in cm	-0.71 (0.014)	-0.44 (.171)	1	
Average Erosion Rate (metre/year)	0.62 (0.042)	0.64 (0.034)	-0.64 (0.034)	1

According to table 2 there is also showing negative relationship between ribbon length value and stability score. But there is a BEHI and erosion rate. Thus the results established the validity of materials and scores that are used in this paper.

Conclusion

Bank erosion rates measured using erosion pin on Kalindri River in Malda over three years were found to be relatively high at source region of the river especially at Najirpur. But the rate is quite low at Sailpur where the vegetation cover was relatively high at right bank of the river than other region. Erosion rates were highest in Monsoon in three study years.

Erosion rates were correlate with number of scores. Average BEHI score is highly correlated with erosion rate (correlation is significant at the 0.05 level). The river Bank of Kalindri at Nimasarighat, Sailpur and Gobarjona sites showing stable condition as the stability scores relatively low for those sites. The study suggests that Najirpur, Lakshmipur and Jotbasanta are highly erosion susceptible sites as the BEHI and Erosion recorded high in these sites.

The source region of the river Kalindri experience high erosion rate due to low vegetation cover, contain sandy soil and poor land use.

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