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Assessment of Stream Bank Erosion Hazard Potential through BANCS Model: A Case Study of Mahananda River at the foothills of the Darjeeling Himalayas

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Abstract

Riverbank erosion is a natural process, but its measurement and prediction is still not an easy task. Bank assessment for non-point source consequences of sediment (BANCS) model is a popular one for evaluating stream bank erosion hazard potential (SBEHP) which includes two procedures, bank erosion hazard index (BEHI) and near bank stress (NBS). In this paper, BANCS model has been applied for about 20km of river Mahananda at the foothills of the Darjeeling Himalayas where bank erosion is prominent. The results show that out of 22 sample points, 14 have high BEHI rating and 4 have a very high and medium rating. In the case of NBS, 7 sample points have low, 9 have moderate and 6 have high NBS rating. Field studies estimated the rate of bank erosion at 2510m^3/year. Less vegetation cover, absence of surface protection at the toe of a bank, higher velocity of water, loose bank material, fluctuation of thalweg, formation of numerous bars in the channel bed are the some of the major causes for bank erosion in this stretch. In order to verify the suitability of BEHI and NBS rating as a predictor of bank erosion, linear regression has been fitted that show a positive relationship between these ratings and observed erosion rate. Hence, this model can be used as a suitable measure for predicting the occurrence of bank erosion of the particular portion of the river.

Introduction

Stream bank erosion is a natural process and has significant geomorphic importance. It is one of the main sediment sources for the formation of many landforms, from floodplain to delta, from meander to bar etc. (Hooke 1979, Lawler 1993, Leyland et al. 2016). Extensive bank erosion also helps to pollute the river-water as a form of suspended sediment which disturbs the biological function of stream especially for fish and micro-organism communities of river-water (Dudley and Karr 2002). From various studies, it has been found that about 80% of total sediment load in world's streams are directly related to stream-bank erosion (Simon and Darby 1999; Sekely et al. 2002; Evans et al. 2006; Fox et al. 2007).The settlement, road, riparian vegetation, agricultural land sometimes vanished on the demand of riverbank erosion, that is why sometimes it may require to investigate the susceptibility of the river bank. Extensive research has been done on stream bankerosion mechanism, types, processes, measurement of stream bank stability and prediction. Thorne (1982, 1999); Simon and Thorne (1996); Darby and Thorne (1996); Simon et al. (1999);Simon (1989, 1992); Schumn and Lichty (1963), etc., Are some pioneer scholars in this field. Bank Assessment for Non-point source Consequences of Sediment (BANCS) is a model developed by famous hydrologist David Rosgen (Rosgen 1996, 2001, 2006, 2008a, b) for evaluating the erodibility potential of stream banks and computing stream bank erosion rates, which encompasses two quantitative tools Bank Erosion Hazard Index (BEHI) and Near-Bank Stress (NBS). This model has widely been used by several scholars in different parts of the world such as Newton &Drenten 2015, Nieber et al. 2008,Nelson et al.2009, Bandyopadhyay et al. 2013, Ghosh et al, 2016. The main aim of the present study is to measure the stream bank erosion hazard potential to predict an annual stream bank erosion rate of a few portions of river Mahananda using Rosgen's BANCS model.

Location of the Study Area

River Mahananda is a dominant left bank tributary of river Ganga in West Bengal region and also a significant river of

North Bengal. It originates from Mahaldiram range near Chimli (latitude 26°55'40"N and longitude 88°14'4"E) in the east of Kurseong, in Darjeeling district at an elevation of 2100 m above mean sea level and descends to the plains near Siliguri. It traverses a distance of about 470 km to join the mighty river, Ganga.In this paper, a small segment of the river channel (26° 41' 35"N, 88° 24'26"E to 26° 49'16"N, 88° 27' 34"E) at the foothills region where a severe problem of bank erosion exists has been taken for the assessment of BEHI and NBS model.The use of the BANCS model has applied for a section of (20 km) river Mahananda, at Gulma and Debidanga mouza in Matigara block and Siliguri in Darjeeling district.22 sample points of the river have been measured and observed from 2015 to 2017.To find out the hydro-morphological variables of the channel, the surveyed channel divided into three segments based on the similarities of channel form and process (Figure 1).Segment I starts from 400m upstream of Gulma Railway bridge to the confluence with GulmaKhola, segment II starts from the confluence of Gulma Khola to the confluence with river Mahismari, segment III starts from confluence of river Mahismari to the confluence with River Balasan in Naukaghat area in Siliguri.

Geography of the Study Area

Mean elevation of the studied portion is 140m from sea level, relative relief is73m. Highest elevation (183m) has found 300m upstream of Gulma Railway Bridge and lower elevation (110m) has found in the confluence zone between river Mahananda and Balasan at Naukaghat area. Geologically, it lies on alluvium and pedogeomorphic point of view, this area is characterized by entisol soil group (Sarkar1989; Acharya & Roy 1989).Upper catchment of the basin is highly degraded in nature where landslide and deforestation are very common (Benerji et al. 1980, Sarkar 1989, Kanungo at al. 2006, Bhattacharya 1999, 2002, 2009, 2011, 2012 a, 2012 b, 2014 Mandal & Mandal 2017). The landslide materials are carried by monsoonal flow through river Mahananda and its adjoining tributaries and deposited in low gradian foothills region. It helps for the formation of numerous bars on channel floor and reduce the capacity of the channeland also create lateral pressure on its surrounding area on the demand of bank erosion and flood (Plate 1, 3). At the Gulma region, river bank mainly composed of sand, gravel, pebble and cobble and the size of the particles are decreasing as moves in the downstream direction (Plate 2). Sudden variation of the bank materials in a particular segment is a typical character of the studied portion which indicates the differentdepositional character of the channel flow in a different period (Plate 3). The region belongs to the sub-tropical monsoonal climate where average annual rainfall varies from 2500mm to 3000mm and 80% rainfall occurs during the monsoonal month from June to September. With increases of rainfall discharge of the channel also increases. The left side of a segment I in Gulma region is covered by tropical deciduous forest, but the amount of vegetation cover gradually decreases as moves in the downstream direction. segment II and III is densely populated and devoid of continuous vegetation cover. The width of the channel also vary greatly, an average width of the channel is 450m, 250m, 110m in segment I, II and III respectively.

Objectives

Following are the specific objectives of the present study:

1. To study the ersion hazard potentiality of river bank using BANCS model
2. To assess the applicability of this model in the study area
3. To measure the total annual bank erosion rate

Methodology

The BEHI assign some numerical value for each and every condition (Table2) which collectively gives total BEHI rating. Determination of Near Bank Stress in a natural river is very important for erosion protection and restoration work (Kean, 2003). In this paper, Rosgen (2006) NBS rating have calculated in level III, method 5. Near bank maximum depth have measured in the field. The cross-sectional survey was done in the sample segment with the help of a total station to obtain the mean depth of the channel. A pre-screening questionnaire had been used in the field during the monsoonal month from the year of 2015 to 2017 for the record of the condition of erodibility variable. In the study area, as the bank condition is different in both bank, that's why the computation of BEHI score have been done separately. Determinations of bank full stage have been done with a repeated field visit, just after the heavy rainfall. The distance from bank top to the surrounding permanent structure and length of exposed erosion pin have measured during pre-monsoon and post-monsoon period to determine the rate of bank erosion from 2015 to 2017. In segment II and III, BEHI calculation mainly has done in the right bank, because the left bank has coveredwith an embankment to protect the settlement in its adjoining area. QGIS 2.18.11, Microsoft Exel 2013 and SPSS have been used for mapping and computing the dataset. Applicability of BEHI protocol depends on a certain assumptions:

1) 50% or less than 50% protection at the toe of the bank.
2) 50% or more of the bank have a bank height of ten feet.
30 50% exposed to bank soil.
4) 50% or more of the bank exhibit stratification.
5) 50% or more of bank exhibit an undercut of 0.5 feet or more.
6) 50% or more of the bank devoid of rooted vegetation.

If and only if, the segment fulfills at least two of the above criteria, the BEHI model can be tested at ease.

Discussion

Bank erosion hazard index (BEHI) is based on the ratio between bankfull heights. bank height, bank angle, the percentage of plant root depth and density, the percentage of an amount of surface protection. BEHI assigns some numerical values for each erodible factor which correspond with overall BEHI rating for a particular region and given the overall stability condition as very low, low, moderate, high, very high or extreme. Higher values of BEHI indicate the greater chances of erosion probability and lower value indicate lower chances of erosion probability. BEHI especially designed for alluvial stream condition.

Bank Height and Bankful Height

Bank height is the vertical distance from the base flow of the channel to the top of the bank. Bankfull height is the maximum height of the water level from thalweg to the bank. In this study region, the attainment of a bankfull stage is very rare, because of the higher gradient of the channel and higher permeability of river bed materials. However, the ratio between bank height and bankfull height is high in segment I (Point A, B, C, D, E) and followed by segment II (J,K,L, M, N, O) and low in segment III, because of its narrow width bounded by embankment which help for rising of water level in comparison to the segment I.

Root Density and Depth

Root density refers to the proportion of exposed bank profile protected by stream roots. Most of the sample bank segment cover medium (20-45%) root density (Figure 3). Maximum (80%) bank root densities have found in the segment I (A, B,C) at the left bank of river channel along Mahananda wildlife sanctuary. Very low root density (20%) have found in sample point G, H, I, R,V (Plate 8).Although, higher root depth does not always indicate higher root density.The density of plant roots mainly depends on the nature of vegetation. For example, Grass, Bamboo roots have higher root density in comparison to the Arjun(*Terminalia arjuna*), Kadam(*Authocephaluscadamba*), Ghoraneem(*Melia azederach*), Chhatian (*Alstoriiascholahs*), Jarul (*Lagerstroemia flos-reginae*), Simul (*Bombax ceiba*), etc. mainly found along the river bank.Point J, K, L, M, and F have very low root depth (Plate 8) but having 40-50% density, as it mainly covered by grass.Root depth in bank profile is very low in segment II and III, because of the absence of mature tree along the bank.

Bank Angle

Bank angle generally refers to the angle of the bank top in relation to the base water flow at the lower portion of the bank or from the toe of the bank profile to the top of the bank. It is found that most bank sample (68%) are having bank angle 61-80degree, 18% bank segment have bank angle 81-90degree and 9% bank angle have less than 60 degrees, only 5% bank samples have to bank angle more than 90 degrees (Table 3). The bank angle of point L is 110 degree which shows the undercutting nature of bank erosion (Plate 7).However, bank angle also varied season to season. During the monsoonal period, when high-velocity water passes adjacent to the bank profile then the angle becomes very high almost nearer to 90 degrees, but when the water level falls then the bank materials start to loosen from the exposed profile and fall at the bank toe and thus lessen the bank angle. Here measurement of bank angle has done during monsoonal period, in 2017.

Surface Protection

Surface protection indicates the percentage of bank toe protected by some structural measurement such as spur, boulder, wooden log etc. (Plate 4). 27% sample bank is having surface protection more than 80%, 18% bank has 50-79% surface protection, 27% bank has less than 10% surface protection in H, I, J, K, L, T sample point. Here, surface protection has done by the boulder(Plate 4). Percentage of surface protection is very high in point A, B, D, F, and G on account of the protection of the Gulma Railway Bridge. It has been found that the surface protection is generally high in the area where settlement is nearer to the bank. Surface protection is very less (<10%) in H, I, J, K, L point.

Results

The BEHI and NBS values of all 22 sample sites have been calculated in Table 3 and 4from which it has been found that 18% bank sample (A, B, C, D) having moderate BEHI Rating, 64% (E, F, G, H,I,N, O,P,Q,R,S,T,U,V) poses high BEHIrating and 18% (J,K,L,M) having very high BEHI rating. Near bank stress calculated based on the ratiobetween near bank maximum depth (d_{nb}) in meter and mean depth (d) in meter, in Level III, No. 5 stage (Rosgen, 2006). Near bank maximum depth have measured directly from the field and mean depth obtained from a cross-sectional survey done in pre-monsoon and post-monsoon period in the concern sample sites. Out of 22 sample sites,6 sample sites (J, K, L, M,P,Q)possesshigh NBS rating, 7 sites, having low NBS Rating, followed by 9 sites under moderate NBS rating (Table 5). The causes of variation of NBS rating indifferent segments are varied. The mean depth of the channel is comparatively low in the segment I in relation to the segment III because aggradational process and formation of bars in channel bed are very prominent in the segment I.

When overall BEHI rating have plotted against measured bank erosion rate, then a positive relationship is found (degree of correlation is 66%) and the relationship is significant at 0.01 probability level (Fig. 14, Table 6). The plotting of observed bank erosion rate against total NBS rating also shows a positive relationship. There is also a positive relationship between BEHI and NBS. Hence, it can be concluded that BEHI and NBS can be used as a suitable predictor of bank erosion of that particular section of river Mahananda in the foothills of Darjeeling Himalayas. The volume of eroded material has been calculated based on the measured bank length multiplying with its height and rate of the eroded bank (Table 4). The observed rate of bank erosion in the segement under study was about 2510.42 m^3/ yr.

Conclusion

Bank Erosion Hazard Index and Near Bank Stress are used for the prediction of the occurrences of bank erosion mainly in alluvial rivers. The study lies in the alluvial fan of the Himalayan piedmont region. The calculation of BEHI and NBS rating and the observed erosion rate show a positive relationship. However, the BEHI rating comparatively has given more fruitful prediction than NBS Rating. Although, only one method out of 7 methods of NBS calculating has applied in the present study. BEHI model considers only five variables, i.e. bank height, bankfull height, bank angle, the root depth, root density and surface protection. But there are many other factors associated with bank erosion, such as loose non-cohesive bank materials, near bank velocity, fluctuating thalweg line etc, but these variables have not been included in this model. If these factors are added in the model then it could be able to yield a more accurate result.

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Table – 1: Fluvio-geomorphological Variables of Mahananda River at the selected sites

Segment	S - I	S - II	S - III
Sample points	A, B, C, D, E, F, G, H	I, J, K, L, M, N, O	P, Q, R, S, T, U, V
Length of the channel (km)	6	5	9
Average width of channel (m)	450	250	120
Channel materials	Sand, gravel, pebble, cobble, boulder etc.	Sand, pebble, cobble, and little amount of silt and clay.	Sand, pebble, cobble, and silt & clay.
Channel gradient	1:240	1:210	1:1000
Type of flow	Semi-permanent	Permanent	Permanent
Bank material composition	Coarse sand, pebble, gravels, cobbles etc. are dominant	Coarse and fine sand, pebbles, gravels, cobbles are dominant.	Coarse & fined Sand is dominant with pebble, gravel, cobble, silt, clay.
Anthropogenic impact	Relatively low	River bed material extraction activities are dominant.	Construction of embankment, bridge, channelization work, supply of waste water, garbage etc.

Table – 2: Bank Erosion Hazard Index (BEHI) (modified from Rosgen 2008a)

BEHI Rating	Bank Height/ Bankfull Height		Root Depth		Root Density (%)		Bank Angle (?)		Surface Protection		Total Score
	Value	Score	Value	Score	Value	Score	Value	Score	Value	Score	
Very low	1.0-1.1	1.5	90-100	1.5	80-100	1.5	0-20	1.5	80-100	1.5	<7.5
Low	1.11-1.19	3	50-89	3	55-79	3	21-60	3	55-79	3	7.6-15
Moderate	1.2-1.5	5	30-49	5	30-54	5	61-80	5	30-54	5	16-25
High	1.6-2.0	7	15-29	7	15-29	7	81-90	7	15-29	7	26-35
Very high	2.1-2.8	8.5	5-14	8.5	5-14	8.5	91-119	8.5	10-14	8.5	36-42.5
Extreme	>2.8	10	<5	10	<5	10	>119	10	>10	10	42.5-50

Table - 3: Calculation for BEHI Score

Seg-ment	Location Point	Bank height /Bank full height		Root Depth		Root Density		Bank Angle		Surface Protection		Total Score	BEHI Rating
		Value	Score	Value (%)	Score	Value (%)	Score	Value (?)	Score	Value (%)	Score		
S-I	A	3.6	10	70	3	75	3	80	5	80	1.5	22.5	Moderate
	B	3.41	10	60	3	70	3	80	5	80	1.5	22.5	Moderate
	C	3.27	10	58	3	70	3	75	5	85	1.5	22.5	Moderate
	D	2.84	10	45	5	55	3	80	5	80	1.5	24.5	Moderate
	E	3.04	10	30	5	40	5	75	5	90	1.5	26.5	High
	F	2.91	10	25	7	45	5	84	7	80	1.5	30.5	High
	G	2.73	8.5	30	5	35	5	83	7	20	7	32.5	High
	H	1.89	7	20	7	20	7	60	3	10	8.5	32.5	High
S-II	I	1.71	7	15	7	20	7	60	3	5	10	34	High
	J	2.95	10	15	7	45	5	80	5	5	10	37	Very High
	K	2.93	10	15	7	50	5	85	7	5	10	39	Very High
	L	2.93	10	10	8.5	40	5	110	8.5	5	10	42	Very High
	M	2.87	10	10	8.5	30	5	85	7	15	10	40.5	Very High
S-III	N	2.05	7	30	5	30	5	70	5	30	5	27	High
	O	2.54	8.5	30	5	30	5	70	5	45	5	28.5	High
	P	1.87	7	25	7	40	5	80	5	60	3	27	High
	Q	1.93	7	30	5	45	5	75	5	50	5	27	High
	R	1.41	5	10	8.5	20	7	65	5	20	7	32.5	High
	S	1.31	5	40	5	40	5	70	5	10	10	30	High
	T	1.45	5	20	7	30	5	65	5	5	10	32	High
	U	1.33	5	20	7	25	7	75	5	45	5	29	High
	V	1.12	3	10	8.5	20	7	65	5	50	5	28.5	High

Table - 4: Calculation for Measurement of Near Bank Stress and Total Erosion Rate (M^3/Year)

Seg-ment	Location point	Near bank height (m)	Mean depth (m)	NBS	NBS Rating	Erosion (m/yr.)	Length of measured bank (m)	Bank Height(m)	Observed Erosion Rate (m^3/yr)
S I	A	3.82	2.21	1.73	Moderate	0.69	34.94	3.83	93.01
	B	3.71	2.30	1.61	Moderate	0.86	35.27	3.71	112.72
	C	3.61	2.42	1.49	Low	0.89	35.33	3.61	113.83
	D	3.21	1.82	1.76	Moderate	0.71	34.98	3.21	80.17
	E	3.61	2.08	1.74	Moderate	1.15	35.86	3.61	149.49
	F	3.51	2.08	1.69	Moderate	1.27	36.10	3.51	161.50
	G	3.21	1.83	1.76	Moderate	1.30	36.16	3.21	151.56
	H	2.88	1.98	1.45	Low	0.87	35.28	2.76	84.45
S II	I	2.98	2.13	1.40	Low	0.55	34.65	1.83	35.01
	J	3.91	1.89	2.07	High	1.56	33.63	3.60	189.49
	K	3.95	1.96	2.01	High	1.96	34.42	3.93	265.17
	L	4.22	1.96	2.15	High	2.43	35.35	3.92	336.15
	M	3.73	1.98	1.88	High	1.42	36.38	3.12	160.83
S III	N	2.72	2.10	1.30	Low	1.37	36.29	2.26	112.16
	O	2.82	1.81	1.55	Moderate	1.20	34.77	2.52	104.74
	P	3.16	1.64	1.92	High	0.59	34.72	2.71	55.34
	Q	3.22	1.68	1.92	High	0.60	31.71	3.05	58.40
	R	2.09	1.46	1.43	Low	0.71	34.98	1.77	44.16
	S	2.26	1.37	1.65	Moderate	0.58	37.77	2.20	48.57
	T	2.51	1.50	1.67	Moderate	0.72	38.05	2.21	60.86
	U	2.25	1.68	1.34	Low	0.74	38.08	2.07	58.29
	V	1.98	1.58	1.25	Low	0.54	34.64	1.83	34.51
Total observed erosion rate 2510.42 m^3/ yr.									

Table – 5: Categories of bank sample under different NBS Rating.

NBS Rating	NBS category	Sample Points
<1.0	Very Low	-
1.0-1.50	Low	C, H, I, N, R, U, V,
1.51-1.80	Moderate	A,B,D,E,F,G,O,S,T
1.81-2.50	High	J, K, L, M, P, Q

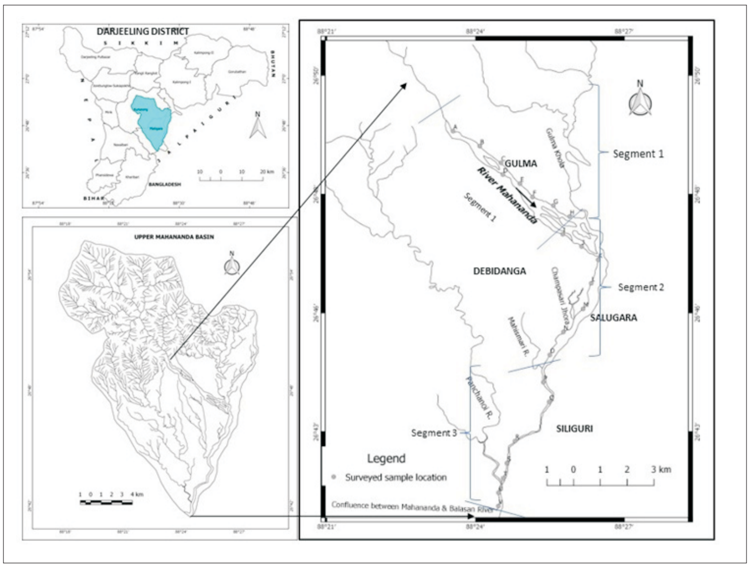

Fig. 1: Location of the Study Area

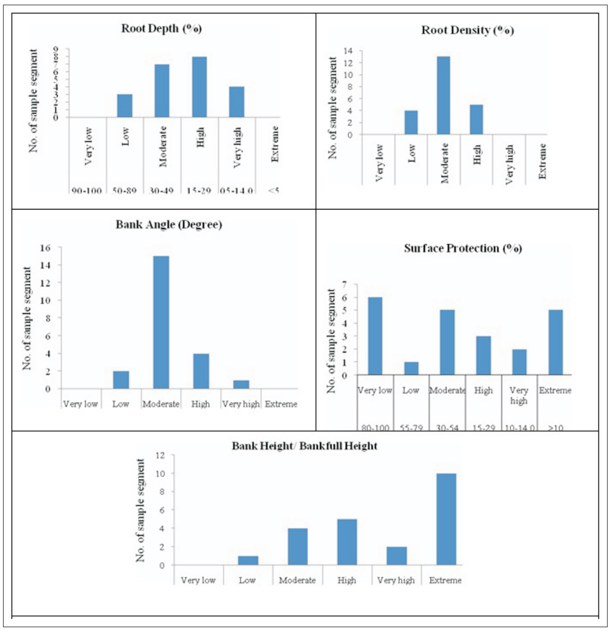

Fig. 2-6: Representation of the Ratings of Different Components of BEHI to the Total Sample Points

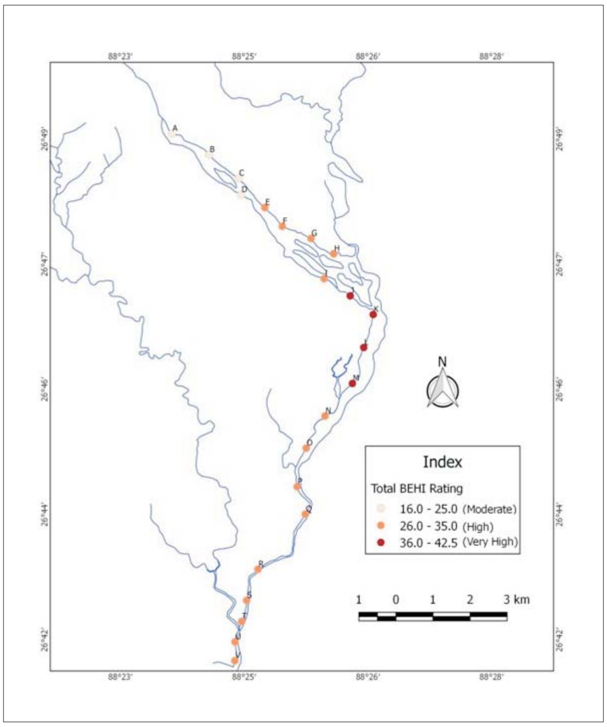

Fig. 7: 7BEHI Ratings in Different Sample Segments of River Mahananda

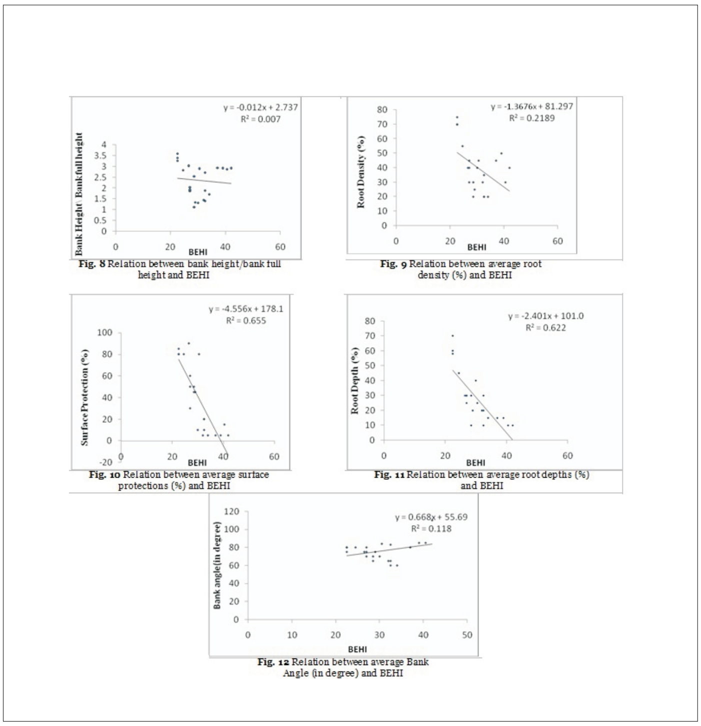

Fig. 8-12: Relations between various Parameters of the River Bank and BEHI Score

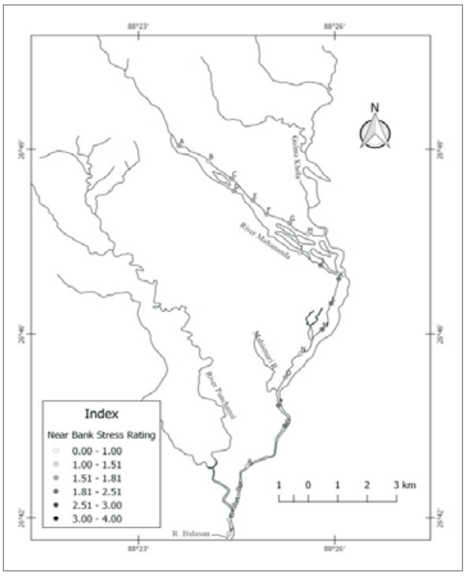

Fig.13: NBS Rating in Different Sample Segments of River Mahananda

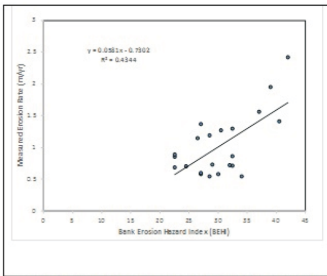

Fig.14: Relationship between BEHI and observed erosion rate (m/yr)

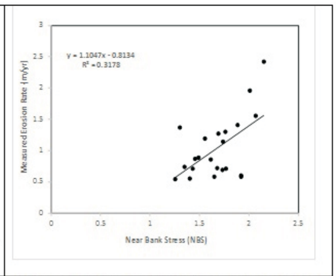

Fig.15: Relationship between NBS and observed erosion rate (m/yr)

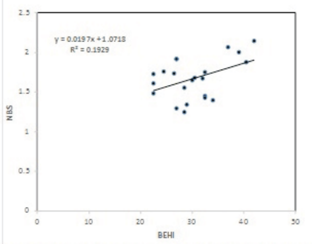

Fig.16: Relationship between BEHI and NBS Rating.

Plate-1: Formation of Longitudinal Bars on Channel Bed at Gulma region.

Plate-2: Riverbank mainly composed of sand, gravel, and pebble.

Plate-3: Exposure of very fine sand below coarse material.

Plate 4 Failure of Erosion Protection Measure adjacent to Gulma Railway Bridge

Plate 5 Bankfull Mahananda River in Siliguri region

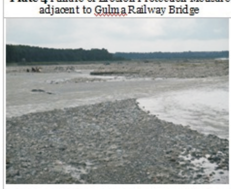

Plate 6 Formation of Longitudinal Bar in the channel of river Mahananda

Plate 7 Nature of Vegetation at 'Point K' with the signs of undercutting.

Plate 8 Vegetationless Bank with high angle (approx 90 degree) during Monsoon

Plate 9 Bank toe protection work done by local people at 'Point L' near Debidanga

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