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Assessment of Channel Bank Susceptibility and Bank Stability of A Braided Reach of River Ganga Near Panchanandapur, Malda

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Abstract

Bank erosion along the course of river Ganga is a major problem of malda district in every rainy season. So, present study focuses on the assessment of bank susceptibility and bank stability of a selected reach of Ganga, mainly left bank of Ganga near panchanandapur. Here the channel is braided which characterised by numerous braids, bars shoals etc. being a braided channel, flow path of water is continuously changing its position which ultimately results huge bank erosion in every year. In the present study three different index including BEHI, NBS and BSI are used for the assessment of bank erosion, near bank stress, and bank stability. A comparative analysis has been done with these three indices to represent accurate present bank condition and bank erosion potential. The result shows, river bank is relatively stable and there is no probability of large bank failure at present condition.

Keywords: BEHI, NBS, BSI, Susceptibility, Braiding Index, Active Channel Width, Sinuosity Index.

Introduction

River bank erosion is a complex geomorphologic process of landscape development[1,2]. It is a dynamic complex process by which soil is detached or deflected, transported and deposited at a relatively distant place resulting of exposure of land at the origin and siltation in river bed[1,3]. Numerous factors which affect erosional processes of river bank including slope, geological structure, soil components of the basin, climatic factors (rainfall, temperature etc.) and anthropogenic activities(channel modification, river linking, land use pattern etc.). But Flow character and geological condition mainly determine Erosional and depositional nature of the river[4]. Problems associated with the river bank erosion are loss of land, loss of vegetation, gradual shifting of river and resultant shifting of local people along the course[5,6,7]**.** Malda district, which is located at the left bank of Ganga, is highly affected by river bank erosion[8]. A vast area of land has been lost to the river Ganga, as thousands of people are rendered homeless[8,9]. Ratua-I, Manikchak, Kaliachak –II and Kaliachak-III have been affected by erosion and subsequent inundation in every year. Planning Commission mentioned in a report nearly 4.5 lakhs of people have lost their homes due to left bank erosion of Manickchak, English Bazar, Kaliachak-I, Kaliachak-II and Kaliachak -III in last three decades[10]. To cope with this problem lots of efforts have been taken at central and state level. Still it becomes headache to local people in every rainy season. In this circumstance proper policy making and its implementation is necessary. Therefore accurate channel assessment is inevitable. The present paper focuses on the bank stability assessment and prediction of erosion potential on the left bank of Ganga, near panchanandapur.

Study Area: Though entire area of malda district on left bank of ganga is facing a great problems of river bank erosion and land loss but here considering the importance and convenience of minute observation a selected length of left bank, near panchanandapur has been adopted as a study area (Figure-1). This area belongs to the Diara physical division of Malda, has long history of land loss, sequential shifting of channel and formation of numerous big braids in the river which influence local people.

During last ten years socioeconomic condition of this area changing rapidly with changing of this morphometry.The area covering 12 km length on left bank with latitudinal extension between 25º 01´58´´ to 24º 56´32´´ and longitudinal extension between 87º 51´15´´ to 87º 59´27´´. The area belongs to the zone of alluvial soil is composed of alternate layers of silt (Fine), clay and sand with average height 25-30m from mean sea level. Geomorphologically it is divided into active flood plain, inactive flood plain, extended flood plain, uplands, piedmont and fan, swampy water logged area etc.

Materials and Methods

The present study has been done through a sequential procedure. The entire procedure is shown in a model in Figure-2.

The data sets are used in the present study are given in Table-1.

For analysis of morphological condition of the reach indices are used are given in Table-2.

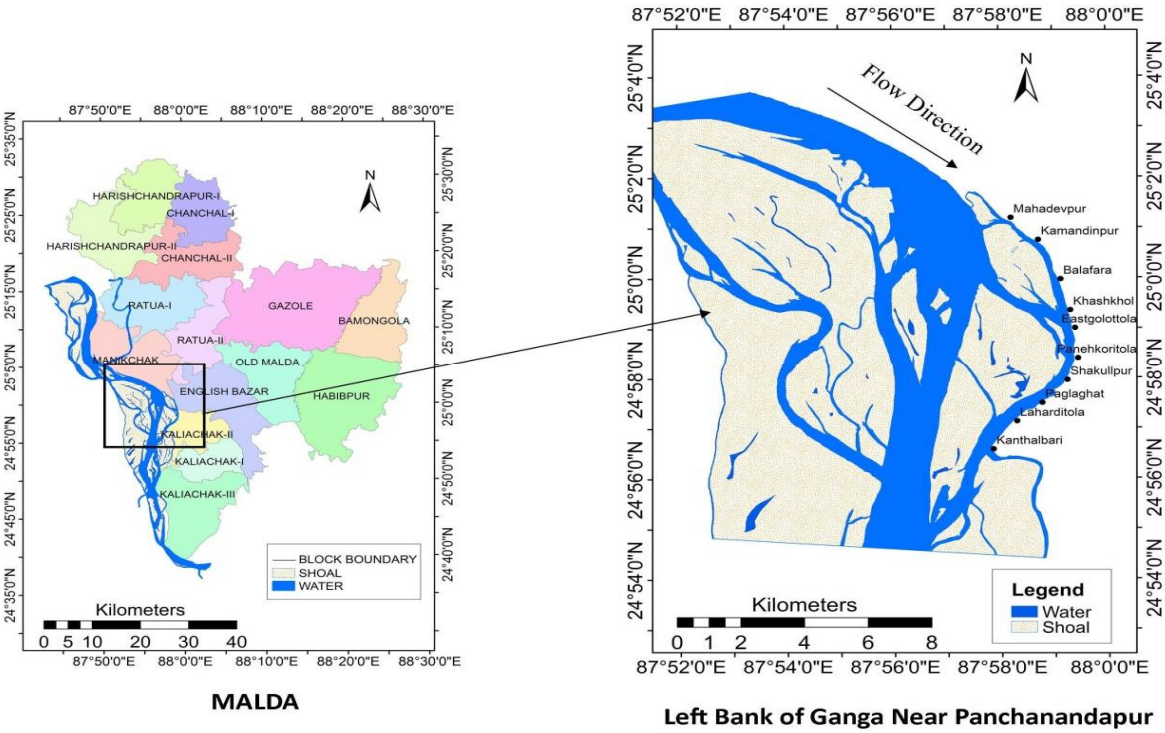


Figure-1
Study Area

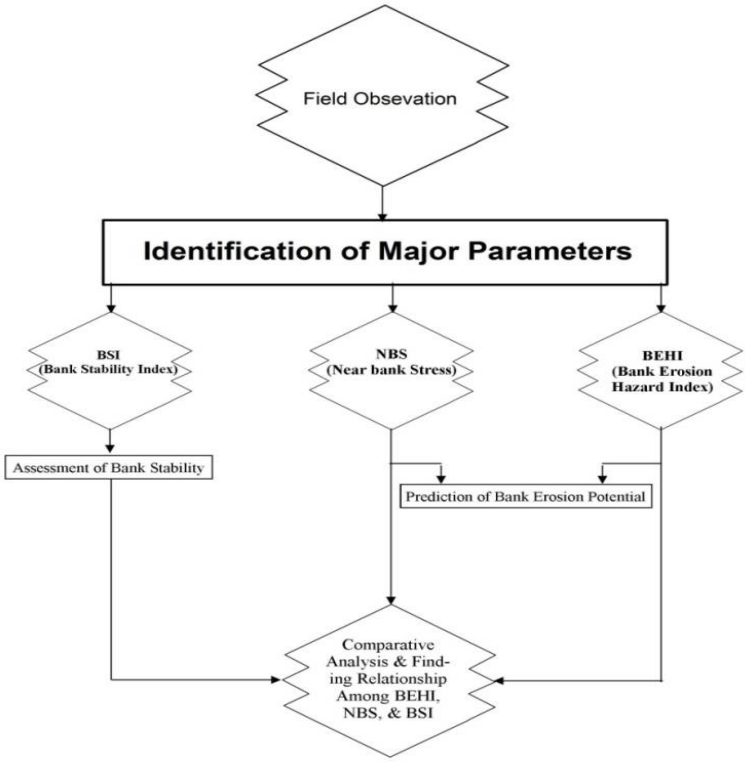


Figure-2
Flow diagram showing a brief methodological proceeding

Table-1
Details of study material

Data type	Source	Purpose
Maps and Images	Google Earth, Landsat Imagery From USGS Earth Explorer, Topographical Map	To locate study area, to show gradual shifting of channel etc.
Bank's Physical Condition	Primary survey	To develop Bank Erosion Hazard index, Bank Stability index, and Bank Stability Index.
Bank Erosion Data	Malda District Census Book 1991	District Bureau of Statistics Office.

Table-2
Details of Various Indies

Index	Formula	Reference
Braiding Index (Brice index)	$B.I = 2*\sum Li/ Lr$ Where; Li = Length of the islands or bars in a reach, Lr= Length of mid way between the river bank of the channel.	[11]
Sinuosity Index (S.I)	$S.I = O_L/E_L$ Where; O_L= Observed(actual) path of a stream and E_L= Expected straight path of a stream	[11]
Active Channel Width (A.C.W)	A.C.W= Total width of the river along a cross section – Total width of braid along that cross section	[12]

Bank Erosion Hazard Index: Bank Erosion Hazard Index is a tool which helps to measure erodibility of an area. In order to develop the BEHI rating, key stream bank characteristics were taken into consideration that would be sensitive to the various erosional processes. These stream bank variables included Figure-3

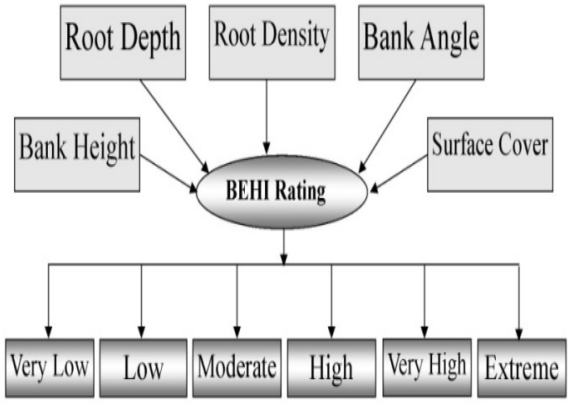


Figure-3
Hypothetical Model for BEHI

Direct Field observations of stream bank conditions were used for identification of stream bank instability associated with bank erosion and various types of failures. The field measured variables were to a risk rating of 1-10 (10 being the highest level of risk) (Table-3). The risk ratings from 1 to 10 represent corresponding category of BEHI risk of very low, low, moderate, high, very high, and extreme[3].

Estimation of Near Bank Stress: Shear stress in channels is the key parameter to predict bank erosion. Here near Bank Stress represents shear stress of bank calculated as bank maximum depth to bank full divided by mean depth[3]. One similar rating scale (Table-4) is used to classify value as like BEHI.

Stream Bank Stabilization Index: Stream Bank Stability Index (BSI) is a composite index like BEHI which represents stability of bank. But unlike BEHI where only selected physical parameters are used, in BSI some natural and some man induced factors which are responsible for bank stability have been taken into consideration[13]. One rating scale is used to categorize this index (Table-5**)**. Value of this index is inversely related with stability that is with increasing index value stability of bank decrease. Lower the value greater the stability.

Results and Discussion

Morphological Characteristics: The study reach belongs to the course of the Ganga upstream of Farakka barrage. In this region the reach has some typical features which continue to change unabated. The morphological characteristics including channel width, channel depth, channel bed topography, channel types, channel pattern, water discharge, and soil type are major contributing factor of morphological change in the study area. Total width of the channel along the cross section changes over the period of time in the reach. The temporal variations of channel width are shown in Table-7.

Table-3
Stream bank conditions used to develop Bank erosion Hazard Index (BEHI)

Risk Rating Categories		Bank Height/ Bank full Ht.	Root Depth/ Bank Height	Root Density (%)	Bank Angle (Degrees)	Surface Protection (%)	Total
Very Low	Value	1.0-1.1	1.0-0.9	100-80	0-20	100-80	
	Index	1.0-1.9	1.0-1.9	1.0-1.9	1.0-1.9	1.0-1.9	5-9.5
Low	Value	1.11-1.19	0.89-0.5	79-55	21-60	79-55	
	Index	2.0-3.9	2.0-3.9	2.0-3.9	2.0-3.9	2.0-3.9	10-19.5
Moderate	Value	1.2-1.5	.49-0.3	54-30	61-80	54-30	
	Index	4.0-5.9	4.0-5.9	4.0-5.9	4.0-5.9	4.0-5.9	20-29.5
High	Value	1.6-2.0	0.29-0.15	29-15	81-90	29-15	
	Index	6.0-7.9	6.0-7.9	6.0-7.9	6.0-7.9	6.0-7.9	30-39.5
Very High	Value	2.1-2.8	0.14-0.05	14-5.0	91-119	14-10.0	
	Index	8.0-9.0	8.0-9.0	8.0-9.0	8.0-9.0	8.0-9.0	40-45
Extreme	Value	>2.8	<0.05	<5	>119	<10	
	Index	10	10	10	10	10	46-50

Table-4
Near Bank Stress Rating Category Scale

Near-Bank Stress Ra ting category	Value
Very Low	<1.0
Low	1.0 - 1.5
Moderate	1.51 - 1.8
High	1.81 - 2.5
Very High	2.51 - 3.0
Extreme	>3.0

Being a braided channel, active channel width is continuously changing over the period (Figure- 4 and 5). But variation in total channel width and active channel width is not same. Variations in active channel width are higher than total channel width. In both of the cases variation is high in station no. 5, 7, and 8.One east word bend developed in that area showing, the river is so sinuous. Sinuosity Index of the reach is 1.20.

According to Leopold and Wolman (year 1964) a river would be sinuous channel when its sinuosity ranges between1.05 to 1.50. Formation of new bars, diminution of old bars and frequent change of bar's position over time are some causes of variations in active channel width of reach.

Channel Depth: The average channel depth in the study reach is 30 ft. and maximum depth in the thalweg point is 50-52ft.

Channel Pattern: River pattern in this region comes under braided channel (Figur-6). Here channel pattern is characterized by multiple channels wherein these channel ways are divided by shoals, bars and islands[14]. Braided index value of the study reach ranges between 3.3-3.4. (2014). This value indicates there is high rate of deposition and number of sands bars, sand islands, and shoal deposits in the river.

Changing dynamics of active flow: The course of Ganga upstream of Farakka barrage has been gradually changing or shifting and being the river is in a meandering state, the process of aggradations and degradation occur simultaneously[15]. Islands get formed upstream due to sediment deposition and the main flow shifts away from the shoal inducing curvature to the stream and formation of secondary current. The outer side of the curved flow undergoes constant erosion and the eroded materials are deposited on the inner side resulting in further growth of the braid and bars. This process of erosion of outer bank and deposition on inner bank may result in further increase in curvature, stronger secondary current and greater erosion of the outer bank causing migration of the meander on the outer side till a state of stability occurs.

In the study reach nature of flow and direction of flow path (active flow) have changed through passage of time. The main reason of shifting of flow path is the continuous changing position of braids and bars. Six maps of reach in different time period (map A-F) have been clearly showing (figure-6) the shifting of flow path and formation of new islands in the river. It has been seen from Figure-6 the map A (1988) that main flow of water was at the left side and one another narrow flow was at right side of the river. But in the map E (2011), there are some new bars formed at left side flow path and in the map D (2001) the braid which was at centre of the river continuously bifurcated widening mid channel flow path and left bank tending to reduce. Map E (2011) and F (2014) showing continuous shifting of bars towards the left bank and most of the water flowing through the middle portion of the river. Continuous deposition of sand bars on the left bank reducing erosion by direct flow.

Table–5
Matrix for Bank Stabilization Index

Bank Condition (Erosional Mechanism)	**Toe and upper bank eroding**			**Toe undercutting**		**Toe stable, upper bank eroding**		
Score	5			3		1		
Length	Length of eroding bank > 50 ft.			Length of eroding bank 20-50 ft.		Length of eroding bank < 20 ft.		
Score	5			3		1		
Slope	Side slope vertical 1:1			Side slope 2:1, 3:1		Side slope 4:1 or flatter		
Score	5			3		1		
Problem trend	Increasing in last 5 years (Land Loss, Property Loss)					Decreasing or stable in Last 5 years		
Score	5					1		
Depth of River	> 3 feet					< 3 feet		
Score	1					2		
Vegetative Cover	Vegetative cover 0-50%			Vegetative cover 50-80%		Vegetative cover 80-100%		
Score	5			3		1		
Mean Height of Bank	Mean height of bank > 20 ft.			Mean height of bank 10-20 ft.		Mean height of bank < 10 ft		
Score	5			3		1		
Soil Type or Texture	Sand			Gravel	Stratified	Clay or loam		
Score	3			2	2	1		
Apparent Cause of Erosion	Light Access Traffic	Obstruction in River	Bank Seepage	Gullying by Side Channel	Bend in River	Road-Stream Crossing, Grade/Shoulder Runoff	Moderate Access Traffic	Heavy Access (foot, Van, etc)
Score	1	1	1	1	2	3	3	5

Sources: Modified from Stream Bank Stabilization Inventory, Land and Water management Division, Department of Natural Resources, Michigan-1997

Table-6
Bank Stability Rating Scale

Value	Category
More than 36	Unstable
30-36	Moderately Stable
Less than 30	Highly Stable

Table-7
Changes of Total Channel Width (in meter) and Active Channel Width of the Reach in Different Time Period

.	1988		1991		1995		2001		2011		2014	
Station no	Total Width	Active Flow Width	Total Width	Active Flow Width	Total Width	Active Flow Width	Total Width	Active Flow Width	Total Width	Active Flow Width	Total Width	Active Flow Width
1	6901.69	3409	4594.99	4031	5087	3057	4365.52	3000	5253.31	3570.58	5117.42	2913.59
2	6441.96	3687	5276.99	3792.53	5587.8	3043.5	5305.96	3468	6649.87	2977.98	6994.36	2864.44
3	7158.4	1833.63	5583.65	3192	5690.67	2691	6610.81	2977.58	6657.85	2783.16	8215.07	2801.45
4	6676.57	3830.11	5827	3948.28	5882.83	2930	7508	3049.49	7972.39	2575.76	9031.7	2533.05
5	3650.73	4493.65	6037.97	3796.42	6142.98	3038	8198	2451	8768.53	2313.02	9054.63	2711.74
6	5985.11	5439.29	6434.54	3768.75	6662	3284	8444.19	2628	8976.52	2957.35	7911.93	2939.91
7	5822.74	4478.33	6734.45	3259.47	7017.19	3135	8424.58	2306.39	8204.48	2785.29	9413.59	5254.76
8	5439.32	3729.48	6894.79	3228	6794	3409	9076.27	2699.53	10993.99	2800	11278.46	4433.6
9	5236.9	2930.83	6876.37	3282	7179.22	3419	11970.96	3816.8	11217.69	3969.74	11293.27	4271.4
10	4565.78	3047.04	7236.36	3560	8100.45	2845	11328	5352.3	10631.48	3111	10593.63	3751.08

Source: Google Earth, Landsat Imagery

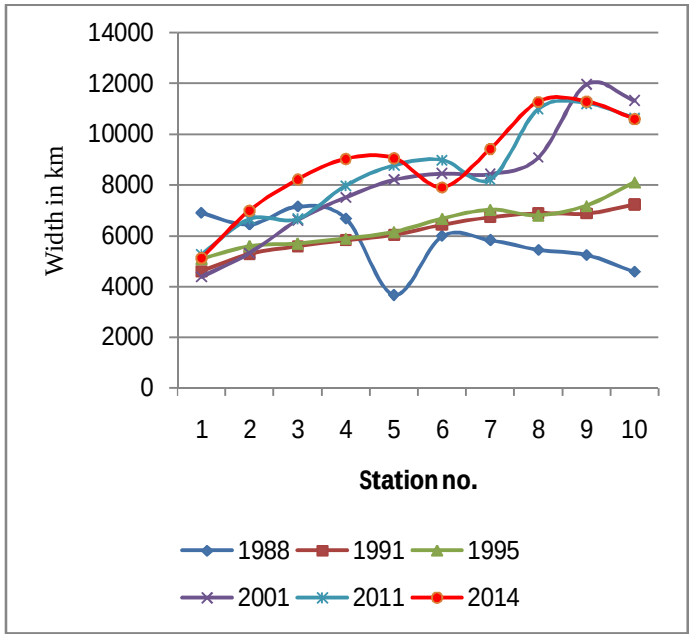


Figure-4
Variations of Total Channel Width in Different Time Period

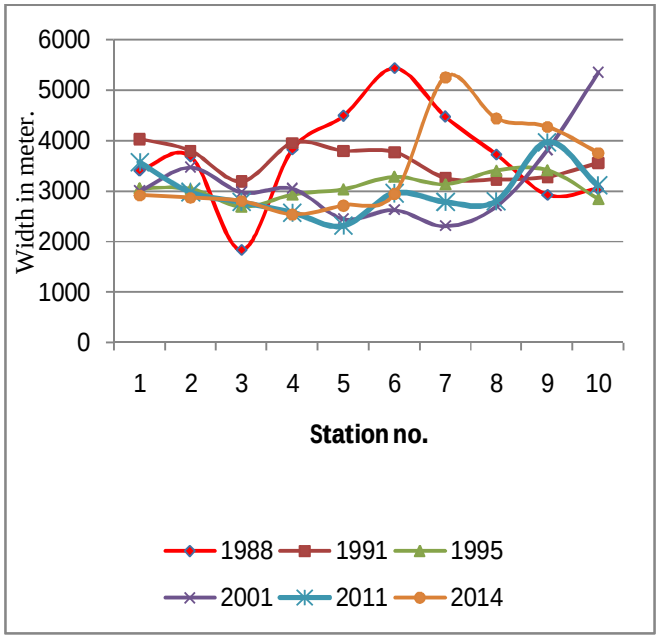


Figure-5
Variations of Active Channel Width in Different Time Period

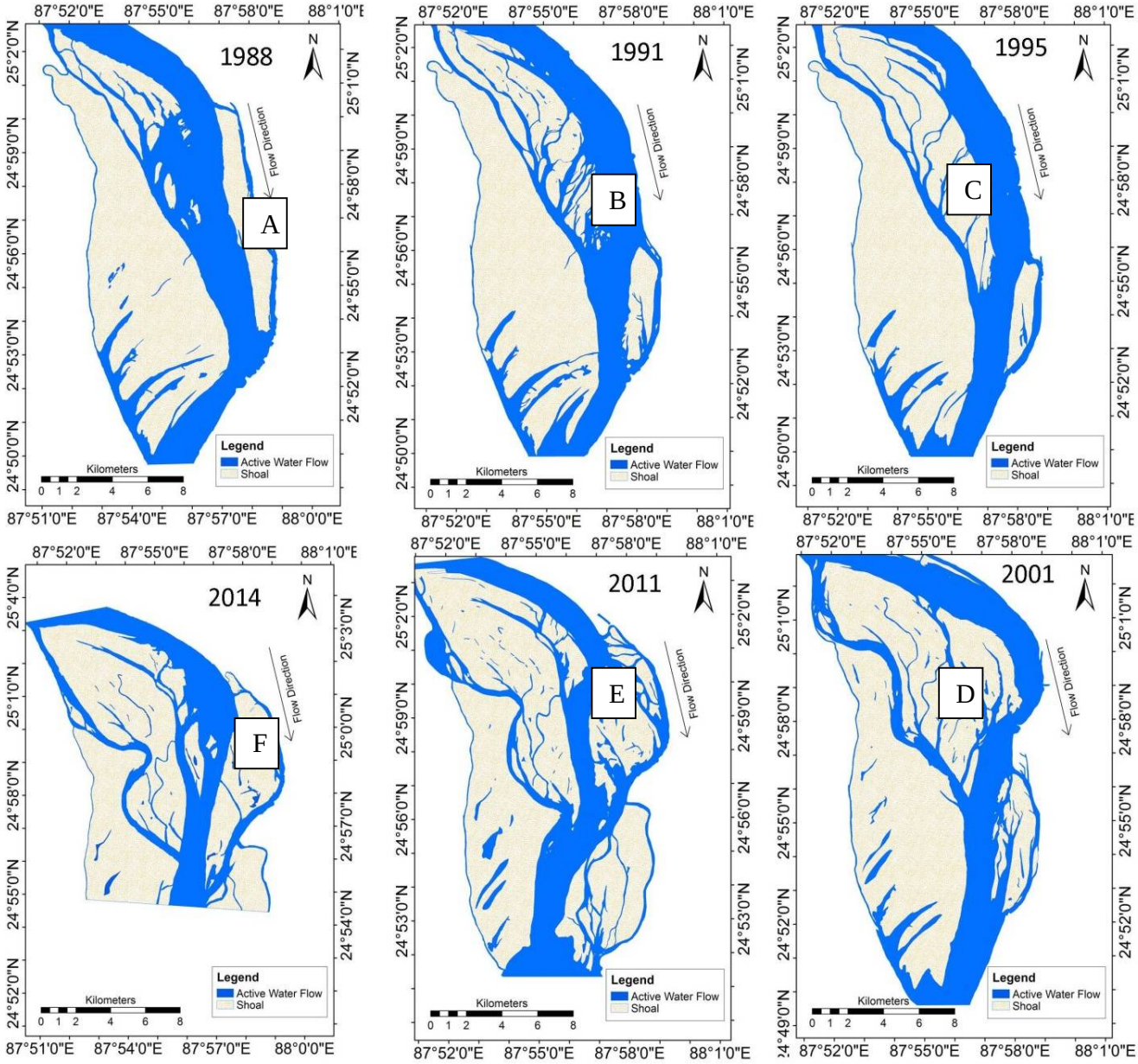


Figure-6
Active Flow Pattern of the reach in different time periods

Bank erosion Hazard Index (BEHI): Bank erosion Hazard Index is calculated along ten selected sites based on previous said method (Table-8). Value of this index represents the study reach is moderate to highly erosion prone area. Out of ten stations, station no.2, 5, 6, 7 and 8 represent high category in BEHI rating Figure -7.

Bank Stability Index: Bank Stability Index is developed at ten stations along the left bank of the reach based on selected criteria. The result shows Table-9 that most of the sites are belonging to moderately stable and highly stable category. As the season is pre-monsoon month so there is low rainfall and low volume of water have no power to strike bank intensely. Only two stations: station no.3 and station no.5 indicate unstable condition.

Near Bank Stress: Near Bank Stress also defined as bank shear stress indicating force exerted by the river on per unit area on bank. NBS is necessary for assessing bank's erodibility and to predict erosion potential. Among ten stations, only station no.5 indicating high NBS, station 4 and 6 has moderate NBS, and rest of stations have low NBS (Table-10).

Table-8
Bank erosion Hazard Index (BEHI) of the Study Area

Station No.	Bank Height/Bank full Ht	Root Depth/ Bank Height	Root Density (%)	Bank Angle(˚)	Surface Protection (%)	Total Score	Risk Rating Categories
1	2.6	0.2	20-25%	25°-30°	25-35%	26	Moderate
2	1.9	0.1	15-20%	45°-50°	10-15%	31	High
3	1.3	0.048	15-20%	55°-60°	10-15%	29	Moderate
4	1.7	0.1	20-25%	>60°	30-35%	28	Moderate
5	2.2	0.08	15-20%	>60°	30%	30	High
6	2	0.08	25-30%	>60°	30-40%	30	High
7	2.1	0.1	25-30%	>60°	30-40%	30.1	High
8	2.7	0.09	20-30%	50°-55°	25-30%	30	High
9	2.3	0.11	20-30%	>50°	20-30%	29	Moderate
10	2.5	0.12	30-40%	>50°	30-40%	29	Moderate

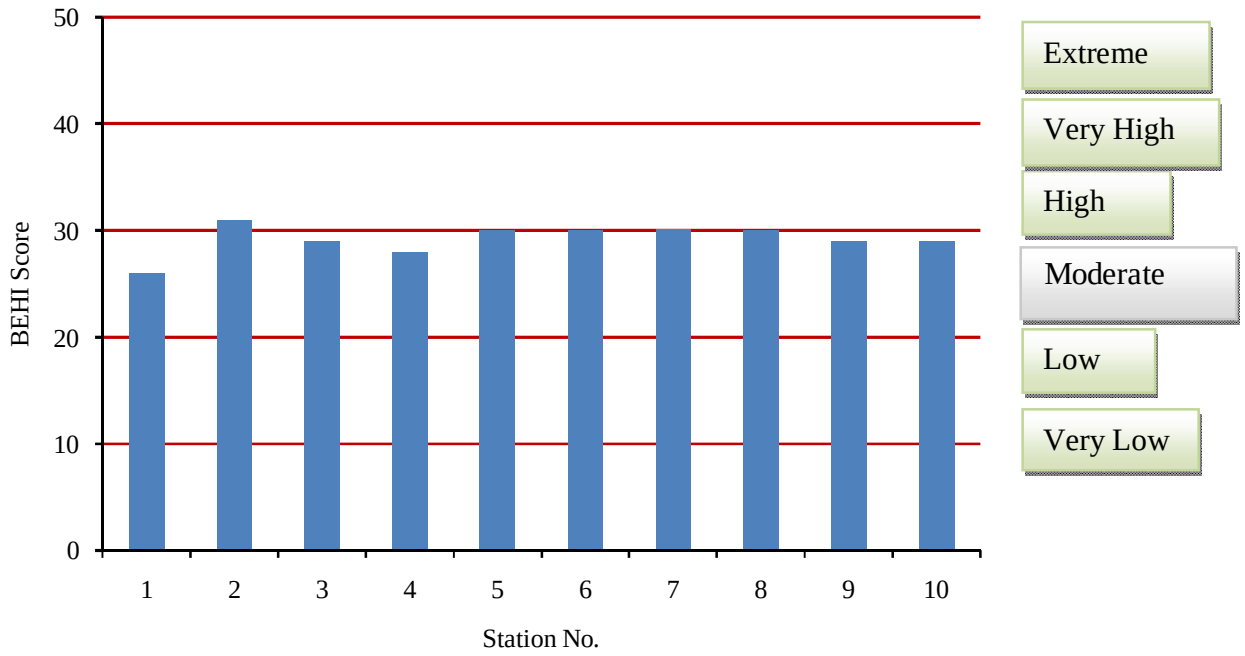


Figure-7
Selected BEHI Results along Left Bank of Ganga, Near Panchanandapur of Kaliachak-II Block

Table-9
Bank Stability Index Category of Different Sites of the Study Area

Site No.	Total Score	Category
1	23	Highly Stable
2	31	Moderately Stable
3	36	Unstable
4	35	Moderately Stable
5	38	Unstable
6	33	Moderately Stable
7	34	Moderately Stable
8	27	Highly Stable
9	27	Highly Stable
10	27	Highly Stable

Table-10
Near Bank Stress Rating Category of Different Sites

Station No.	Near Bank Stress(Near Bank Max Depth(ft)/ Mean Depth (ft)	Risk Rating Categories
1	1.3	Low
2	1.3	Low
3	1.35	Low
4	1.6	Moderate
5	1.9	High
6	1.7	Moderate
7	1.4	Low
8	1.2	Low
9	1.5	Low
10	1.4	Low

Estimation of Bank Erosion: Here one attempt has been made to predict annual total bank erosion (figure-8) of the reach by using Near Bank Stress index (NBS) andBank erosion Hazard Index (BEHI). This basic method is adopted from Rosgen, 2011

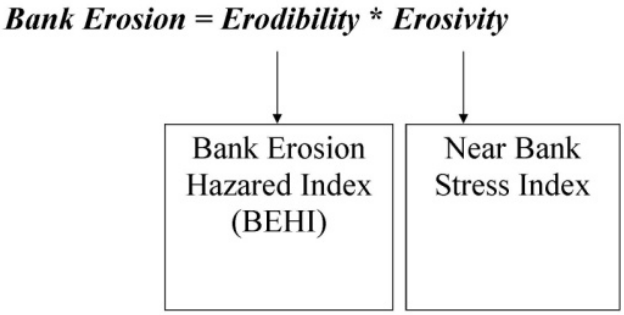


Figure-8
Hypothetical Model of Bank Erosion Potential

Relationships of BEHI and NBS to Predict Annual Stream bank Erosion Rates from Colorado Data for Streams Found in Sedimentary and/or Metamorphic Geology developed by Rosgen, (1993)

The result shows total erosion is 0.128 (tons/yr. /ft.) per unit length (Table-11). This statistically proved value would be validated when it would be compared with the actual erosion rate value. Actual erosion can be measured by lateral movement of bank or may be other processes. Since both Near Bank Stress index (NBS) and Bank erosion Hazard Index (BEHI) are calculated on the basis of physical characteristics of bank which are not remain uniform in all time rather these change with changing season. So this type of measurement may be erroneous.

Association among BEHI, BSI and NBS: All of three index BEHI; BSI and NBS are more or less indicators of bank's erodibility condition. Comparative correlation among them also represents more accurate bank condition than only one index.

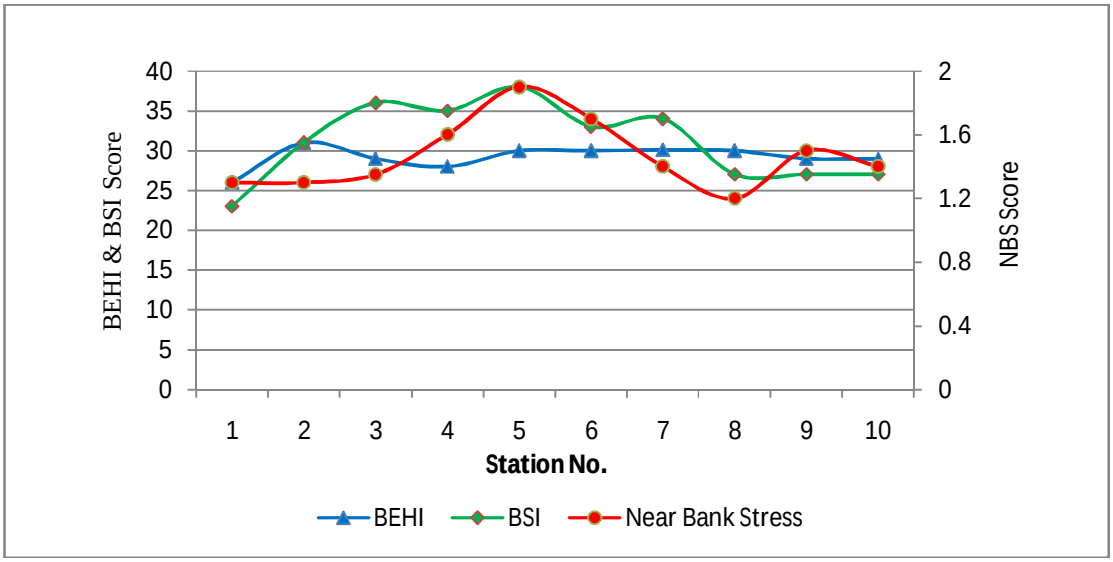
The correlation value indicates BEHI and BSI is moderately correlated correlation value 0.454571) each other but BSI and NBS is highly related (correlation value 0.61614). The correlation value of BEHI and NBS is not significant at desired level (table-12).

The result of comparative analysis of BEHI, NBS and BSI shows only station no.5 relatively unstable, high bank erosion prone and there is high near bank stress (Figure-10).

Erosional Mechanisms and Processes: Though actual Erosional process is the combination of several Erosional mechanism but three dominant Erosional mechanisms (rilland gully, toe erosion, seepage and piping) have been identified in the study area (figure-11). Among various erosional mechanism toe erosion and gully erosion are main Erosional processes in this area.

Table-11
Total Bank Erosion Calculation of the Study Area

Stream: Ganga			**Total Bank Length**		**Date - 5-04-2014**	
Station No.	**BEHI Risk Category**	**Near Bank Stress Risk Category**	**Erosion Rate (ft/yr)**	**Length of Bank (ft)**	**Bank Height (ft)**	**Erosion Sub Total (ft3/yr)**
1	Moderate	Low	.075	4035.43	10.76	3256.59
2	High	Low	.175	4068.24	12.3	8756.89
3	Moderate	Low	.075	3707.34	20.57	5719.49
4	Moderate	Moderate	.175	4986.87	19.61	17113.69
5	High	High	.475	2066.92	22.21	21805.49
6	High	Moderate	.290	1171.65	16.01	5439.86
7	High	Low	.175	3772.96	15.87	10478.45
8	High	Low	.175	5839.89	16.09	16443.67
9	Moderate	Low	.075	2690.28	14.38	2901.47
10	Moderate	Low	.075	3620.25	14.92	4051.05
Sum of sub-total erosion for each BEHI/NBS combination					Total Erosion (ft3/yr)	95966.65
					Total Erosion (tons/year	4620.61
					Total Erosion per unit length (tons/yr/ft)	0.128



Figure–9
Comparison of BEHI, NBS and BSI

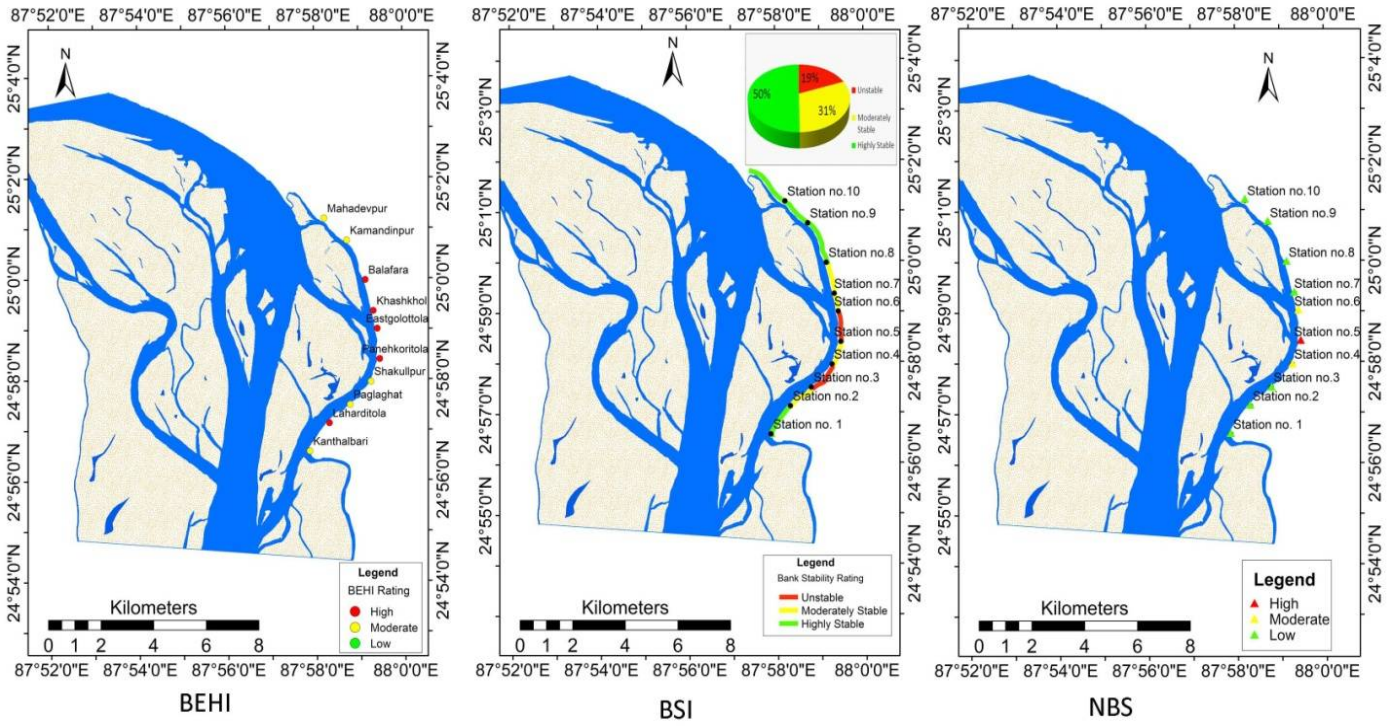


Figure-10
Comparative analysis of BEHI, NBS and BSI

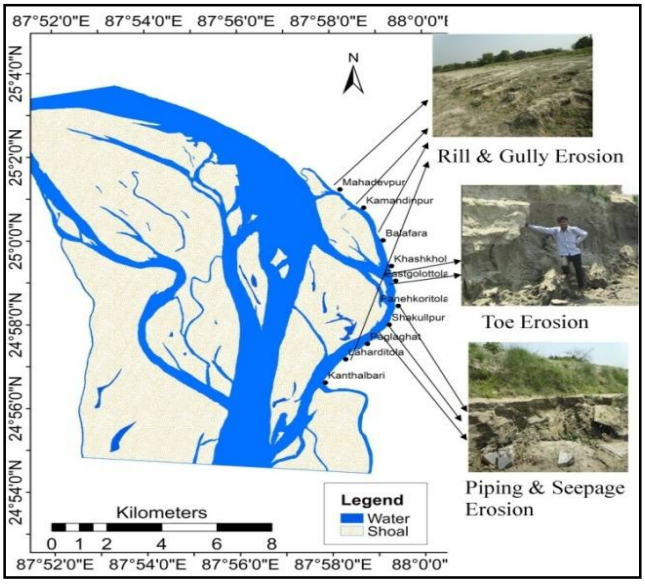


Figure-11
Dominant erosional processes of the reach

Natural causes of erosion: Soil texture, components, layer arrangement and flow character are important factors of natural causes of erosion. In the study area, 2.20% is coarse sand, 31.60% is fine sand and 39.00% is silt[16]. It is statistically proved that with increasing percentage of silt and sand in the soil, the void ratio of soil increases which continuously decreases soil cohesion and plasticity[17].

Another natural reason of soil erosion in this area is stratified layer of soil. The bank of the reach is formed with alternate layers of silt (Fine), clay and sand (Figure-12). These soils consist of layers of materials of various textures, permeability, and cohesion. When cohesion less layers are interbedded with cohesive soils, the erosion potential is determined by the characteristics of the cohesion less soil. In the study area cohesion less sand layer is overlaying by silt and clay layer which is more prone to toe erosion.

Table-12
Correlation among BEHI, BSI and NBS

	BEHI	BSI	NBS
BEHI	1	0.454571	0.134632
BSI	0.454571	1	0.616114
NBS	0.134632	0.616114	1

Man Induced Causes: Human activities are also responsible for river bank erosion. Human is an active agent which brings about modification of natural landscape. This modification sometimes accelerates bank erosion. In the study area river bank erosion is also cause of some human activities such as – heavy access traffic, excess agricultural activities near bank of the river and excess soil extraction for brick making (Figure-13).

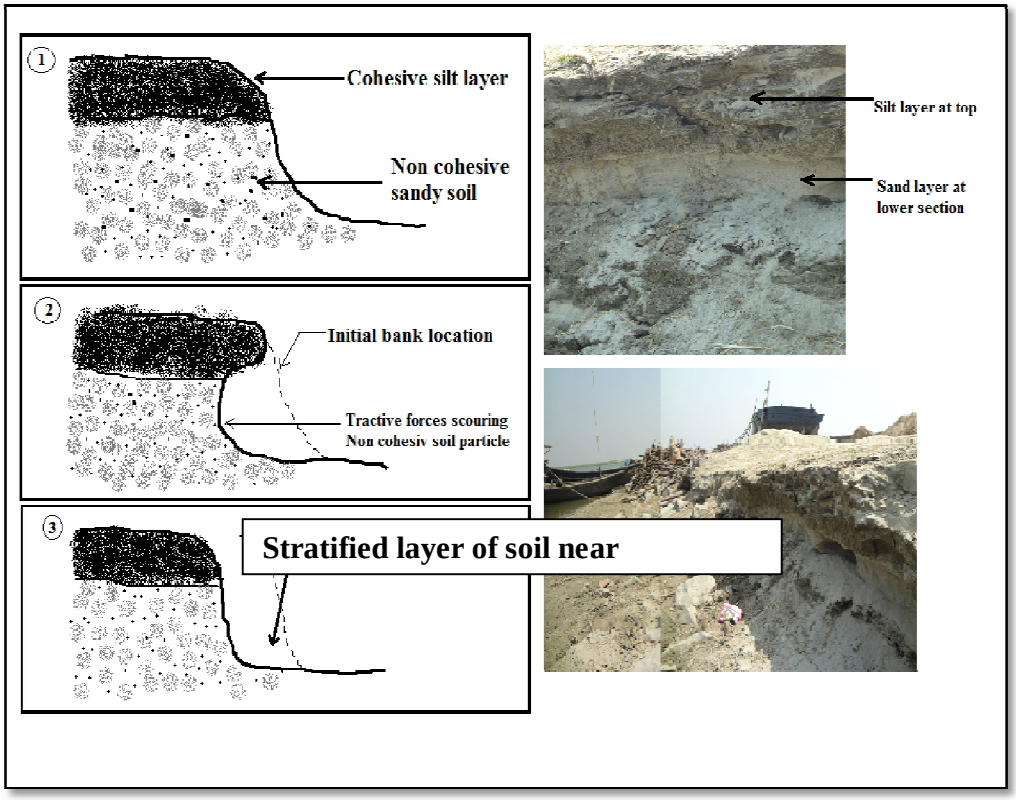


Figure-12
Erosional processes in a stratified layer of soil

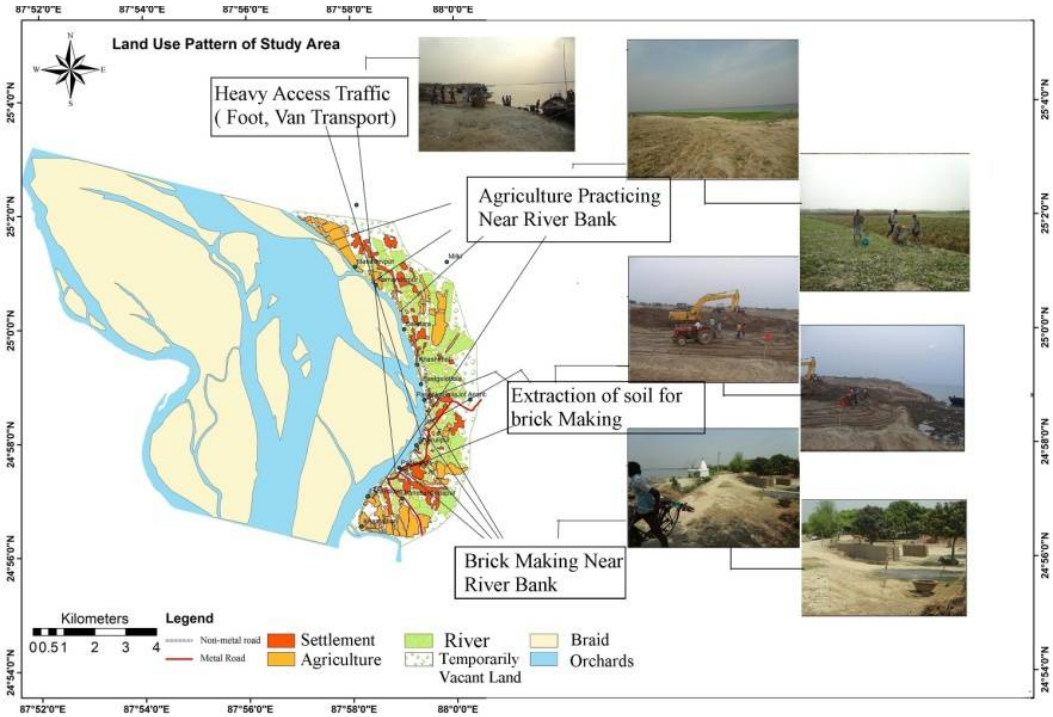


Figure-13
Relationship of land use pattern erosional processes of the reach

Conclusion

Finally it can be concluded that River bank erosion is the major problem of Ganga which brings about significant change in landscape and affecting local people. The result of this study indicate that historic change in flow path, soil type, composition and hydro modification refers to changes in physical characteristics of river and its bank, which influenced erosional and depositional nature of river in the study area. It is believed that bank erosion in this area was a primary result of the toe undercutting or channel degradation incurred by human activities. Bank Erosion Hazard Index and Bank Stability Index are used to determine erodibility of bank and stability of bank respectively. After analysis of these indexes it can be said that present condition of river bank is relatively stable. The area did not see massive bank failure in last ten years. Loss of property, problems of relocation, and creation of environmental refugees due to bank erosion are tending to slow down and socioeconomic condition becoming stable, no big threat to people living nearby. So this study can help the planner and decision makers to undertake management strategies on bank erosion on the basis of present condition of bank. Field measurement for estimating bank erosion is essential for validation such semi quantitative models which are constructed here, so a limitation in here with this paper.

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