Journal of Geographic Information System, **2011, 3, 85-97**
doi:10.436/jgis.2011.31006 Published Online January 2011 (http://www.SciRP.org/journal/jgis)

Morphodynamic Changes of Bhagirathi River at Murshidabad District Using Geoinformatics

Surajit Panda, Jatisankar Bandyopadhyay
[1] *Department of Remote sensing & G. I. S, Vidyasagar University, West Bengal, India*
E-mail: *surajit.rsgis@gmail.com, jatiban@gmail.com*
Received October 23, 2010; *revised November* 10, 2010; *accepted December* 2, 2010

Abstract

The channel of Bhagirathi River is the branches off from the Ganga at Nurpur (lower course of the Ganga). Bhagirathi River is one of the main rivers in Murshidabad district. Analyzing the image of the Bhagirathi River in Murshidabad district through the year 1970, 1977, 1990, 2000 and 2006, it is found that significant changed has been occurred in souththern part of the river and less change is found in the middle part which is close to the Berhampore town. Toposheet of the year 1970 is also compared with the image data to observe the change. Water discharge, soil types and transportation of sediment is the major contributing factor of morphological changes like bar or shoal, ox-bow Lake, meander etc. Maximum erosion takes place at Dear Balagachi and after Baidyanathpur. A cut-off has take place at Baidyanathpur in 1984 [1]. It is found from the study that there is a possibility of natural meander cut-off at Dear Balagachi and near Majayampur. The traditional bank protection works, concrete walls, cemented stone and brick, play a significant role in the modification of the hydraulic aspect of the discharge values and in the interference in the water dynamics of erosive and depositional phenomena both upstream and downstream.

Keywords: Ox-Bow Lake, Meander Cut-off, Sinuosity Index (S. I), Meander Belt, Braiding Index Etc

1. Introduction

Meandering streams are one of the few morphological system for which an abundant historical record exists of changes of channel pattern and associated flood plain erosion and deposition. Despite the evidence from survey, process measurements, image analysis floodplain stereography are just the beginning to construct realistic process models of meandering stream evolution. Here discussed the combines simulated bank erosion and channel migration. Such simulation modeling has both practical and theoretical utility for prediction of channel and floodplain changes, validation of theoretical process models, and increased understanding of the sedimentological structure of fluvial deposits with implication for groundwater flow.

The model discussed here has three major components: (1) The model flow, bed topography, and sediment transport in meandering streams, (2) The component is a relationship between near-bank velocity and corresponding rates of bank erosion and lateral migration and (3) The marriage of a realistic model of meandering with floodplain sedimentation is the novel contribution. The objective of the study is as follows:

- To investigate the morphological aspects such as channel geometry, fluid dynamics and hydraulic geometry of the basin area.
- To study the changes of channel capacity width, depth, meander, etc.
- To study the discharge of water and sediment and also its effect on bank erosion.
- To propose the rational management for the abatement of erosion and protection for river bank.

2. Background to the Study

It is found that significant changed of Bhagirathi river bank has been occurred in southern part of the river and less change is found in the middle part which is close to the Berhampore town.

Meander evolution relying on alternate bars has two deficiencies as a universal explanation for meandering. They predict a non-meandering platform for channels two narrow for development of alternate bars (the curvature-based model allows meandering under such conditions). Therefore, both curvature-forced variations in velocity and depth and alternate bars may control development of meanders. The natural wavelengths of meandering associated with the curvature forcing and alternate bar forcing may not be same, leading to possibility of multiple wavelength scales. In many cases migrating alternate bars occur in meandering channels. Migrating bars do not affect average bank erosion rates in systematic manners.

Another, and possibility related observations is that alternate bars migrate freely in low amplitude sinuous channels but can become suppressed in high-amplitude sinuous channels, possibly reforming in very high-amplitude meanders. Such locking and suppression may induce systematic variations in flow and bed topography that is not accounted for by liberalized models and which could affect bank migration rates. This possibility is addressed further in lated and natural meanders. The model also is clearly inadequate in the case where the width/depth ratio is grater enough for braiding to become important.

2.1. Objective

1) To investigate the morphological aspects such as channel geometry, fluid dynamics and hydraulic geometry of the Bhagirathi river basin area.

2) To study the changes of channel capacity width, depth, meander, etc.

3) To study the discharge of water and sediment and also its effect on Bhagirathi river bank erosion.

4) To propose the rational management for the abatement of erosion and protection for Bhagirathi river bank.

3. About Study Area

The Murshidabad district of West-Bengal is situated on south of Ganga River. The latitudinal and longitudinal extension of the district is 23^0 43'N to 24^0 52' N and 87^0 49'E to 88^0 44'E respectively. Bhagirathi is the Branch of the Ganga River from Nurpur, 25 Km below Farakka, and flowing way to the South it leaves from the district just north of Plassey **Figure 1.**

The river Bhagirathi has bifurcated the triangle shaped district and divided it into two broad geographical regions of almost equal area and having a striking difference in their geology, in the agricultural and habitation pattern and even in the religions of their inhabitants. The general inclination of the district west of the Bhagirathi is from north-west to south-east; but in the tract east of Bhagirathi, the lines of drainage are somewhat irregular as the main rivers do not uniformly takes this direction.

The tract of Bagri, lying east of Bhagirathi is covered with recent alluvium, consisting of sandy clay and sand along the course of the rivers, and fine silt consolidating into clay in the flatter parts of the plain; sometimes the areas form saucer-like depressions. A bank of stiff clay, gravels and calcareous modules called ghuting forms, the junction of the alluvium and higher grounds on the west of Bhagirathi. In the north-west of the district are some isolated clay hillocks such as channel geometry, fluid dynamics.

4. Methodology

After collecting the data; the toposheet, Google earth map and block map (district) are rectified (ERDAS IMAGINE −9.0). Then, the images (3-years) are registered (ERDAS IMAGINE −9.0) with respect to toposheet. Next, the images are subseted (ERDAS IMAGINE −9.0 and ArcGIS −9.2) to delineate the study area. After that the Bhagirathi River is subseted from the three images and the water body is masked from sub set images (ERDAS IMAGINE −9.0). Next the river is digitized from toposheet and Google map (ArcGIS −9.2). After that, overlapping (superimposing) the all river layers and digitized major changes (ArcGIS −9.2). On the other hand, RS & GIS are applied to know the length by digitizing the river and central line. Again, the RS & GIS are applied through measurement scale to measure the length of bar and to know the angle of curvature and also the radius (ArcGIS -9.2).

4.1. Analysis of the Bhagirathi River Bank Shifting

The different sections of the analyses parts are:

- Identify the changes parts of Bhagirathi River.
- Various model and process analyses (Meander geometry) for proving the shift of the river.
- Possible cause of bank erosion.
- Protection and Management.

5. Changes Parts of Bhagirathi River

Since the installation of the Farakka in 1975, there has been an increase in the discharge of the river. This has caused several cut-offs to be formed in the river Bhagirathi.

5.1. Cut-off at Dear-Balagachi

Dear-Balagachi is the only conspicuous meander to be formed in the upper course of the river. At Dear-Balagachi it is seen that the angle between the two tangents

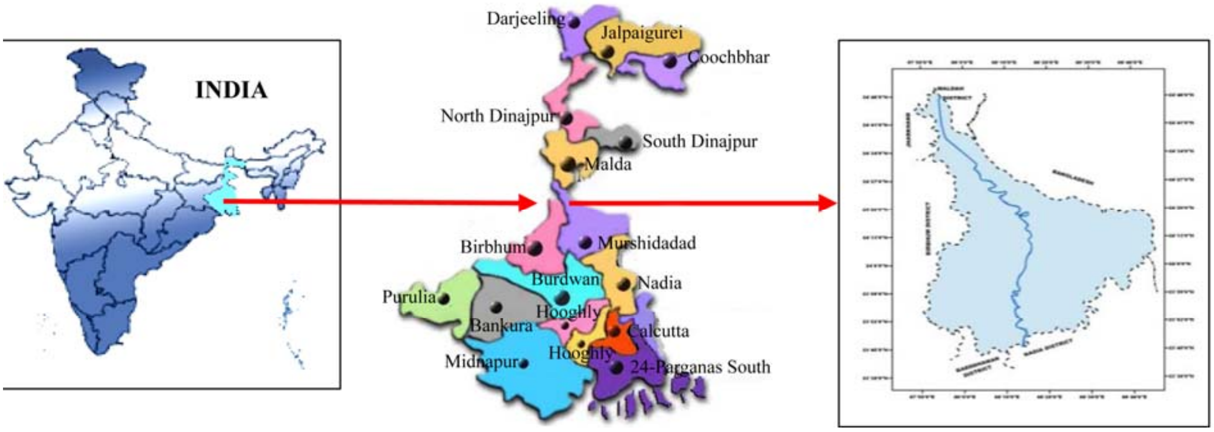
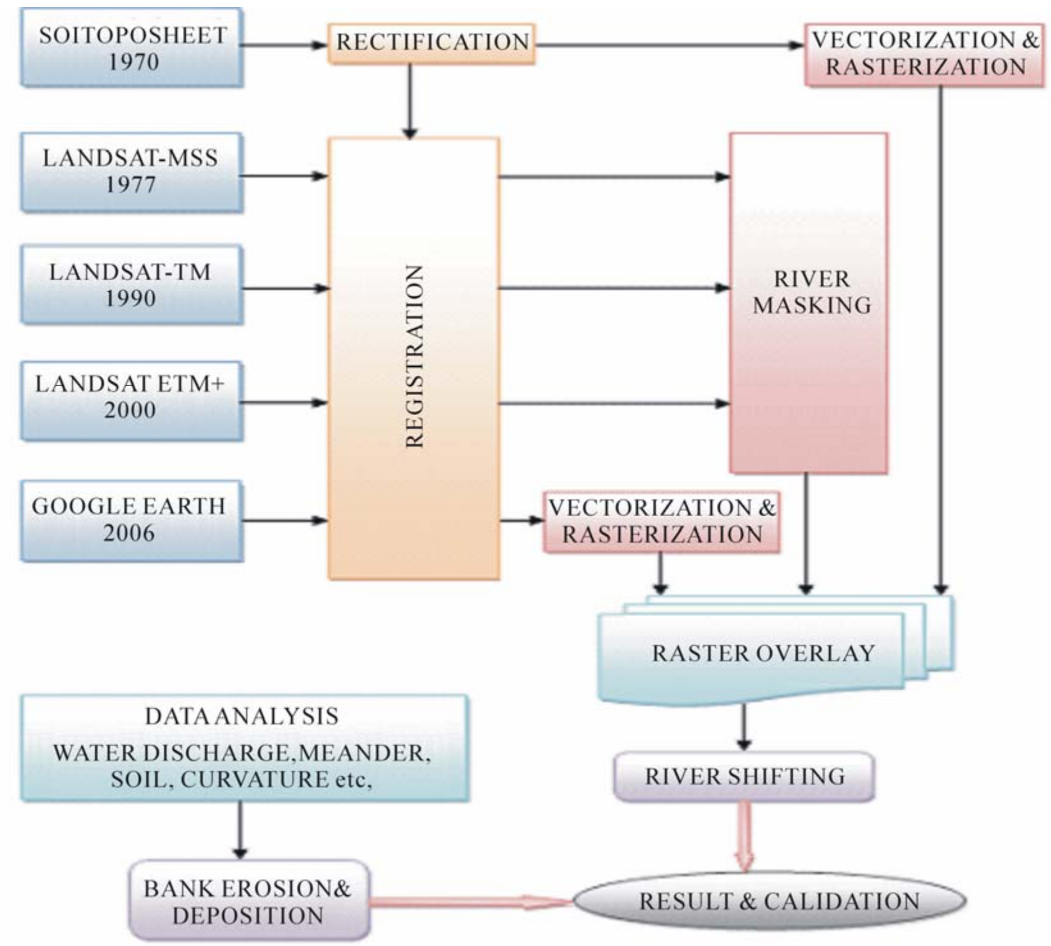


Figure 1. Location map of study area.



Flow chart of methodology

and the distance between the two tangents is decrease, so there is a chance of a cut-off in near future (**Figure 2**). Dear-Balagachi loop which is downstream from the Feeder Canal outfall. The erosion near the neck of the loop during the year 1993-1994 has been observed.

5.2. Cut-off at Baidyanathpur

The cut-off at Baidyanathpur took place during the freshets of 1984, which is situated about 95 km downstream of the Feeder Canal outfall. The river at Baidyanathpur

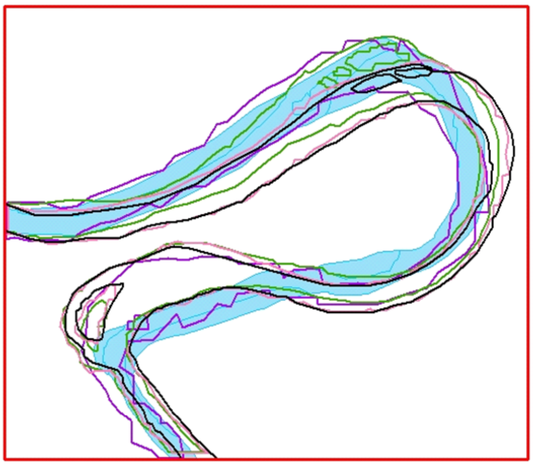


Figure 2. Cut-off at Dear-Balagachi.

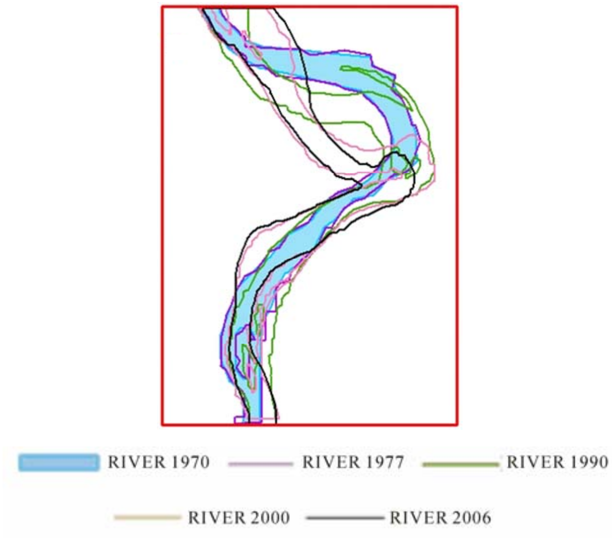


Figure 4. Bhagirathi river near Majhyampur.

formed a wide loop with a very narrow neck. Severe erosion took place at the neck of the loop, causing the cut-off to take place (**Figure 3**). Due to the reduction in length of the river the hydraulic gradient increases. The velocity was very high and the same volume of water following through the narrow neck at Baidyanathpur reached the breaking point and produced a cut-off.

By the study of the Bhagirathi River the major change is take place near the Majhyampur (**Figure 4**), Saktipur, Baidyanathpur, and upper part of Plassey and near the Barhampur moderate change take place.

6. Various Model and Process Analyses

6.1. Sediment Transport Model

If the sediment supplied is in excess of transport capacity deposition occurs and vice-versa. It is important to note that the sediment transport capacity includes only the bed material load and not the wash load which contributes about 80 present of suspended load from the sources mentioned earlier. It is this bed material load which settles largely on the bed in case of the channel load washed in. Also, a large concentration of fine material in suspension alters the transport capacities of a channel.

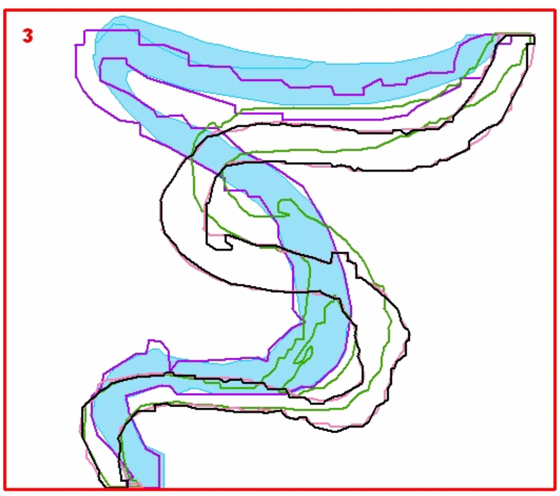


Figure 3. Cut-off at Baidyanathpur.

Total load of stream = (bed material load) + (wash load) (1)

Bed material load = (bed load + suspended load) (2)

The Bhagirathi draws an uncontrolled amount of sediment from the Ganga at Jangipur. The average transport capacities of the reach at individual section for discharge below the **Table 1**.

Here the sediment supplied is more than transport capacity, so the deposition occurs and some bars or shoal is form.

Near Berhampore, significant shoaling characteristics are absent (show the **Table 2**) because the excessive load has already deposit in previous reach. Here the river is low sinuous (wave length is big) is called "Secondary" meanders.

Table 1. Showing average sediment transport and load capacity.

Discharge (cfs)	Average transport capacity tons/day	Suspended load at Jangipur tons/day
20000	3581	6616
40000	16891	24439
59000	35127	39313

Table 2. Showing the average sediment transport capacity.

Discharge (cfs)	Average transport capasity tons/day
20000	2780
40000	15000

The sediment transport capacity at Jangipur in different year is computed shown in **Table 3** using the equation:

$$G= aQ^b \quad (3)$$

[2] a and b constant value.

6.2. River Width

By the measurement or river width from Jangipur to upper part of Plassey, (near about 1.5 km interval) it is found the variation below the **Figure 5** of river width. The variation of river width is happened due to variation of river bank erosion and deposition that indicate the river bank change.

6.3. Meander Geometry

***Sinuosity Index* (*S.I*):**

SI = meandering length/ straight length (4)

[3] Within the study area (Jangipur Barrage to upper part of Plassey), the sinuous is vary from 1.49 to 1.53 (**Figure 6**) from 1970-2006. In this reach, the river has winding as well as straight course when the sinuosity index is mainly within 2, in most part of the river. This is due to the less sinuous course of the river, mainly from Hazarduary to Baidyanathpur. In this part the river sinuosity index is minimum −1.05 from **Table 4**. Wherever the river has less sinuous course or the sinuosity index is within 1.25 (**Figure 6**), the river is in between the straight and regular stage.

In some places like at Dear-Balagachi, Majhyampur, Baidyanathpur, Saktipur and upper part of Plassey area the river has winding course and here the sinuosity index has increased which is within 1.75 to 2.10. But the sinuosity index at Baidyanathpur is about 2.10 (**Table 5**). This is because the river has straightened its course after the cut-off. At Diar-Balagachi a conspicuous meander has been formed with a wide loop. The river has found a sinuous curve and the sinuosity index here is 4.819.

From this study it can be concluded that when sinusity index is with in 1.25, the river is in between the straight to the regular stage. When the sinusity index is more than 1.5, the river is in the Meander stage. When it is above 2.5 the river is in the tortuous stage.

6.4. Braided Channel

A braided channel pattern is characterized by multiple channels wherein these channel ways are divided by bars and islands and are always shifting within highly erodible river banks. The characteristic features of braided channel pattern include unstable bars and islands; temporal changes in their (bars and islands) positions and size and shape from one day to the other, from one month to the other and from one season to the other.

The braided stream channel contains bars and island, and the degree of braiding can be expressed by the reach length that is divided by one or more islands or bars'(chorley, *et al*. 1985), J. C. Brice (1964) has devised a brading index to determine the degree of brading-

Braiding Index (Brice index) = $2\sum L_i / L_r$ (5)

where, $\mathbf{L_i}$ = Length of the islands or bars in a reach, $\mathbf{L_r}$= Length of mid way between the river bank of the channel.

From the computed, it is clearer that the bars of Bhagirathi River are unstable, because the Braiding Index values are not constant**.** It varies from 0.045507262 to 0.776291999. It is also observed that the major instability in the year 2006, which indicate the change in behavior in the river (**Figure 7**).

Cut-off has occurred for Ratio Value (rc/W) ranging from 1.0 to 12.0 .Most of the cut-off occurred at (rc/W)

Table 3. Computed sediment transport capacity at Jangipur.

op	Discha-rge (Q) in Cusec	a	Q^b	Sediment Discharge (G)tons/Day
16/9/1963	43746	0.00000184	7677126249	14125.9123
19/9/1964	40702	0.00000184	6583874553	12114.32918
13/9/1965	43436	0.00000184	7561711888	13913.54987
11/8/1967	40735	0.00000184	6595249733	12135.25951
31/8/1968	40319	0.00000184	6452615277	11872.81211
9/8/1995	42740	0.00000184	7305963917	13442.97361
31/8/2005	46378	0.00000184	8694499655	15997.87937
30/8/2006	43482	0.00000184	7578779294	13944.9539

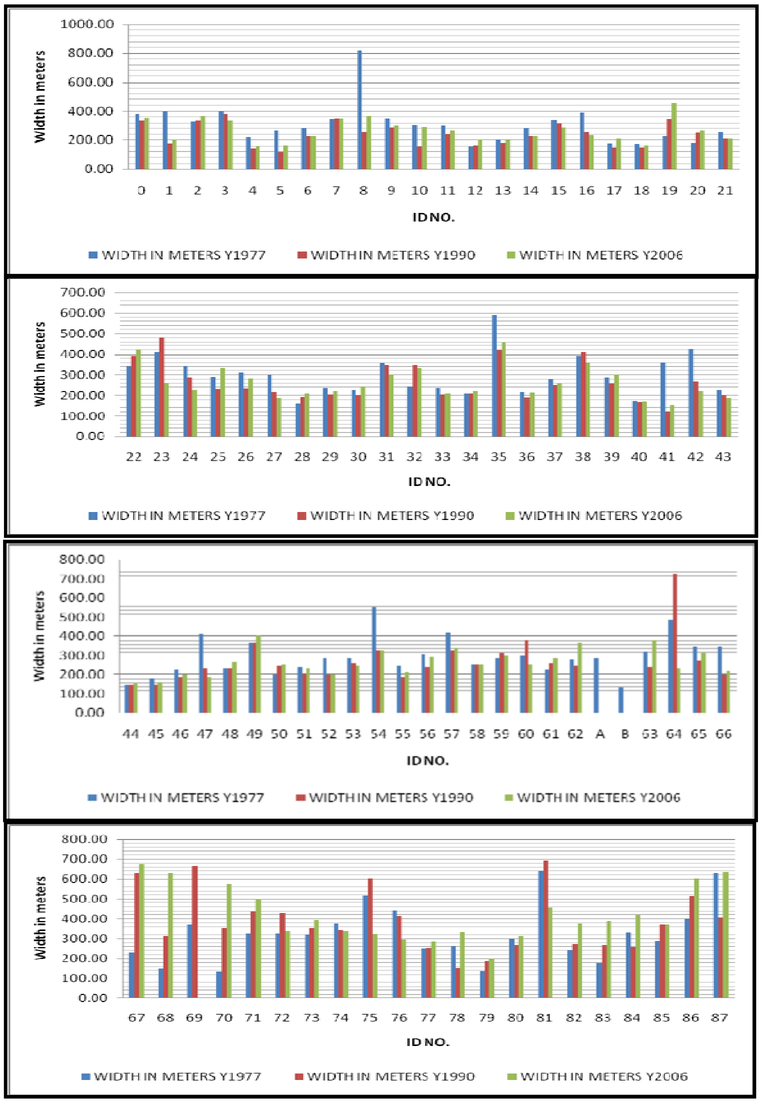


Figure 5. Width of the Bhagirathi river (1977 to 2006).

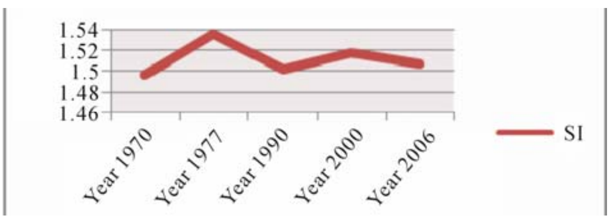


Figure 6. Sinuosity index.

value between 1 and 4 [4]. Where, R_c= Centre line radius of bend.

$$W = \text{Average width (River)} \quad (6)$$

In the Murshidabad district, the natural cut-off of Bhagirathi River takes place at near Baidyanathpur (1977-1985) and as a response oxbow lake. Now from the figure **Figure 8**, It is clear that there is a chance of

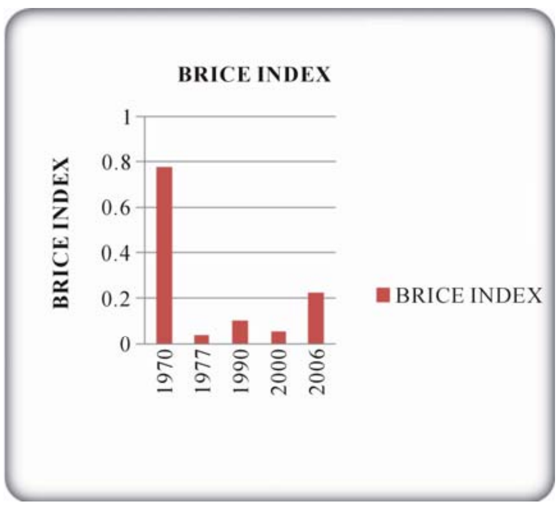


Figure 7. Show braiding index.

Table 4. Computed sinuosity index of Bhagirathi river from 1970 to 2006.

Years	Channel Length(m)	Straight Length(m)	SI
1970	131137.2652	87,628.95	1.496506223
1977	134457.9416	87,593.84	1.535016034
1990	132195.0939	88,036.14	1.501600224
2000	133438.3782	87,959.05	1.517051133
2006	132580.7542	87,953.67	1.507393104

Table 5. Computed sinuosity index of Bhagirathi river in 2006 at different location.

2006			
LOCATION	Meandering length (m)	Straight length (m)	Sinusity index
Dear-Balagachi	10244.88603	2,125.77	4.819369979
Hazarduary to Baidyanathpur	23512.49477	22,219.23	1.058204658
Baidyanathpur	7835.480839	3,714.81	2.1092531
Majhyampur	3878.752157	2,215.33	1.750870645
After Majhyam-pur	23163.21025	17,780.23	1.302750685

natural meandering cut-off at Bhagirathi River near the Majhyampur and after some years near Birendranagar and Dear Balagachhi. Most of the Cut-off of Bhagirathi River has occurred for Ratio Value (r_c/W) ranging from 0 to 1.0 **Figure 9**.

6.5. Meander Belt of Bhagirathi River

$$Mb = \left(2+\sqrt{3}\right)r_c \quad \textbf{(7)}$$

From the above equation when Mb will be '0' neck distance will be '0' and Ox-Bow lake will be formed [2]. The meander Belt at Majhyampur was 294 m. in 2006, which is gradually changed to wards "0". So the natural cut-off of Bhagirathi River takes place at near Majhyampur in future and a small Ox-Bow lake will be formed **Figure 10**.

Where, Mb = meander Belt, r_c = Centre line radius of bend.

$$\zeta_W = \frac{2w\psi}{\left(1u+1d\right)} \quad \textbf{(8)}$$

[5] where, ζ_w = curvatures, ***W*** = Channel width, ψ = The angular change in direction at the node (meander), $\boldsymbol{l_u}$ and $\boldsymbol{l_d}$ = the distance to the adjacent upstream and downstream nodes **Figure 11**.

By the computing the curvature **Table 6** of some places with the help of above Equation (1), the study showed the variation of river curvature (**Table 7**). The variation of river curvature is may be due to the variation of river bank erosion and deposition that indicate the change of river bank pattern.

7. Possible Cause of Bank Erosion

7.1 Water Discharges

The main reason for Bhagirathi River bank erosion is due to fluctuating water discharges from the Farakka Barrage through the feeder canal at Jangipur **Figure 12**. After the construction of Farakka barrage about 2.62 Km. (1975), the 40000 cusec (near about) of water drainage from Farakka up stream to Bhagirathi River through the Feeder canal (38.30 km). The high discharge (Source: CPT) of water increase the stream power (Ω = wQS) and high stream power increase the Bank erosion.

7.2. Soil Types

The Murshidabad district belongs into the zone of alluvial soil **Figure 13**. The characteristics of the soil also have an important bearing on the extent of erosion. The banks of Bhagirathi River have been formed by alternate layers of silt (Fine), clay and sand **Figure 14**(**a**). Incoming high velocity of water colliding with the sand particles and chemical composition of Alluvial soil like pH= 6.21, C= 0.31%, N= 0.33%, Fe_2O_3 = 3.92%, Al_2O_3= 5.8%, R_2O_2= 9.98%, CaO= 0.54, coarse sand 2.20%, Fine sand 31.06% and Silt 39.00% etc [6]. Hydration means the observation of the water. In this process water molecule enter into the crystal of the mineral. Consequently rocks gets fragile and brakes ultimately. By this processes Hematite turns into Limonite. So the soil is acetic and erodability.

$$2Fe_2O_3 + 3\ H_2O \rightarrow 2Fe_2O_3,\ 3H_2O\downarrow$$

$$Al_2O_3 + H_2O \rightarrow Al\ (OH)_3 + H_2\uparrow$$

The soils present along the banks have pore spaces, which gets filled up with water of river during the monsoon months. When this water gets inside these pore spaces, the soil particles (chemical composition) are liquefied [liquefactions] **Figure 14(b)**. But when the water is return back to the river in the winter months, the soil particles are loose and the reaches are fall, causing bank erosion.

7.2.1. Stream Power

One of the most important expressions of the hydraulics of flow in a channel is Stream Power (Ω).

$$\Omega = w\ Q\ S\ kg/m^3/s \quad (9)$$

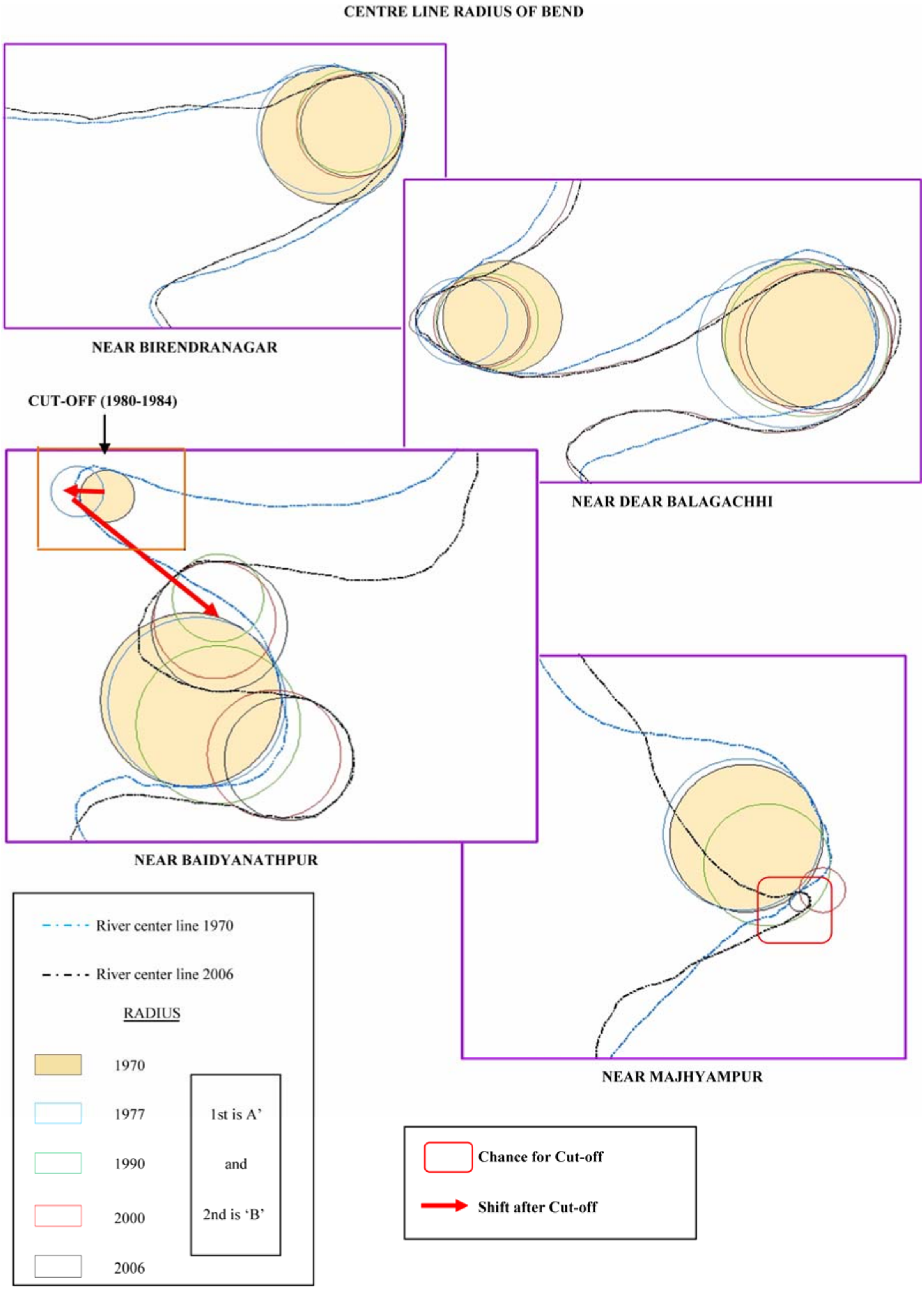


Figure 8. Centre line radius of bend.

Table 6. Computed curvature of Bhagirathi river at different location.

Location	1970	1977	1995	2000	2006
NEAR BIRENDRANAGAR	1.113034685	1.659209799	1.437617075	1.353941103	1.617594373
NEAR DEAR BALAGACHHI (L)	2.515306168	1.698947308	1.620270084	1.867711283	1.349637805
NEAR DEAR BALAGACHHI (R)	0.547237175	0.818645949	0.864777938	1.036722485	1.061546405
NEAR BAIDYANATH-PUR (U)	2.797150164	3.648345267	2.212639589	0.605117345	0.672352606
NEAR BAIDYANATHPUR (L)	2.781338251	1.381316138	1.885878387	0.603339203	0.535284009
NEAR MAJHYAMPUR	0.653372071	0.871284163	1.192884455	0.890750508	2.234147625

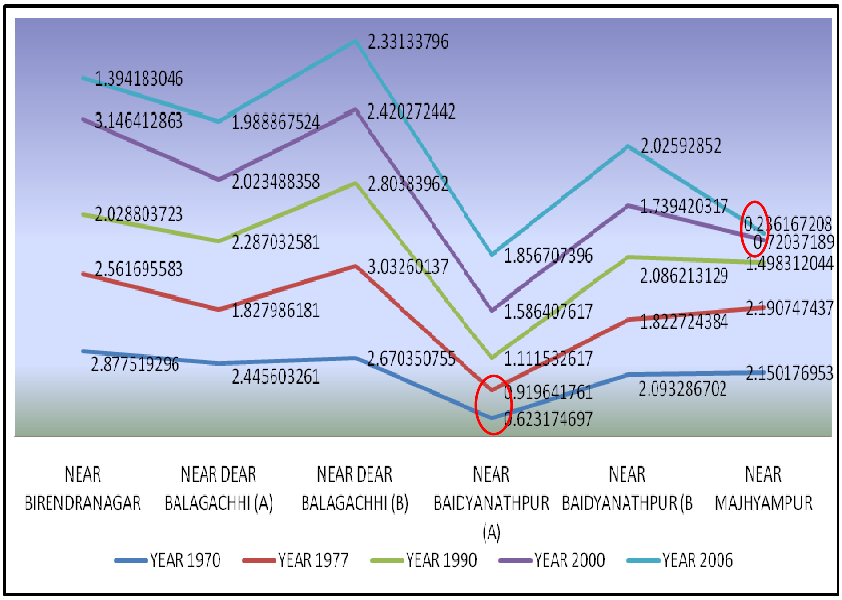


Figure 9. Meandering cut-off.

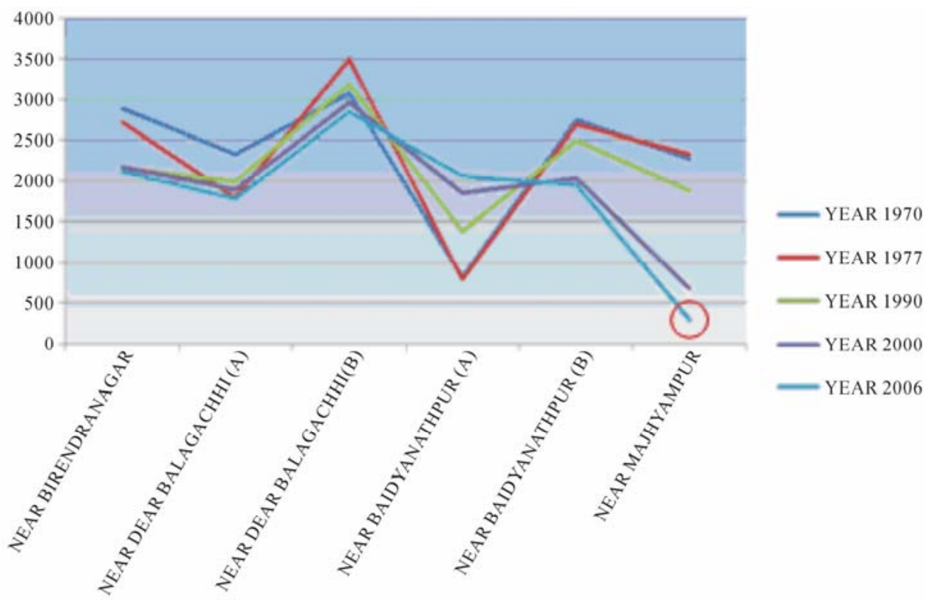


Figure 10. Meander belt.

Table 7. Computation of meandering cut-off.

Years	Location	Perimeter (metres)=2πr	Radius (rc)	A. Width (metres)	Ratio Value(rc/W)	Mb
1970	NEAR BIRENDRANAGAR	4861.06298985000	773.35093020341	268.75612312400	2.877519296	2886
	NEAR DEAR BALAGACHHI (A)	3920.56087061000	623.72559305159	255.03956549600	2.445603261	2328
	NEAR DEAR BALAGACHHI (B)	5170.08857185000	822.51409097614	308.01724811700	2.670350755	3070
	NEAR BAIDYANATHPUR (A)	1387.56421502000	220.74885238955	354.23269528600	0.623174697	824
	NEAR BAIDYANATHPUR (B	4622.65387067000	735.42220669750	351.32416696800	2.093286702	2745
	NEAR MAJHYAMPUR	3818.87259157000	607.54791229523	282.55716887800	2.150176953	2267
1977	NEAR BIRENDRANAGAR	4584.96487263000	729.42622973659	284.74352479600	2.561695583	2722
	NEAR DEAR BALAGACHHI (A)	3029.25673251000	481.92720744477	263.63832099500	1.827986181	1799
	NEAR DEAR BALAGACHHI (B)	5886.84726883000	936.54388367750	308.82525241000	3.03260137	3495
	NEAR BAIDYANATHPUR (A)	1344.81373562000	213.94763975773	232.64237110300	0.919641761	798
	NEAR BAIDYANATHPUR (B	4544.93214180000	723.05738619546	396.69046651600	1.822724384	2698
	NEAR MAJHYAMPUR	3931.66808993000	625.49265067068	285.51563726000	2.190747437	2334
1990	NEAR BIRENDRANAGAR	3632.33051001000	577.87076295614	284.83325236300	2.028803723	2157
	NEAR DEAR BALAGACHHI (A)	3355.91736420000	533.89594430455	233.44483537400	2.287032581	1993
	NEAR DEAR BALAGACHHI (B)	5370.29155261000	854.36456518796	304.71235194900	2.80383962	3189
	NEAR BAIDYANATHPUR (A)	2328.79002981000	370.48932292432	333.31394633500	1.111532617	1383
	NEAR BAIDYANATHPUR (B	4205.26931052000	669.02011758273	320.68637109100	2.086213129	2497
	NEAR MAJHYAMPUR	3150.02443526000	501.14025106409	334.46988097300	1.498312044	1870
2000	NEAR BIRENDRANAGAR	3651.19947574000	580.87264386773	184.61424774400	3.146412863	2168
	NEAR DEAR BALAGACHHI (A)	3178.45716437000	505.66363978614	249.89698498000	2.023488358	1887
	NEAR DEAR BALAGACHHI (B)	4989.55946009000	793.79355046886	327.97694034900	2.420272442	2962
	NEAR BAIDYANATHPUR (A)	3113.99124876000	495.40769866636	312.28272825300	1.586407617	1849
	NEAR BAIDYANATHPUR (B	3414.69132434000	543.24634705409	312.31459221400	1.739420317	2027
	NEAR MAJHYAMPUR	1149.75163380000	182.91503265000	253.91750436600	0.72037189	683
2006	NEAR BIRENDRANAGAR	3569.46568700000	567.86954111364	407.31347495800	1.394183046	2119
	NEAR DEAR BALAGACHHI (A)	2985.75679900000	475.00676347727	238.83278180700	1.988867524	1773
	NEAR DEAR BALAGACHHI (B)	4807.85487700000	764.88600315909	328.08885551100	2.33133796	2855
	NEAR BAIDYANATHPUR (A)	3471.19077900000	552.23489665909	297.42699238300	1.856707396	2061
	NEAR BAIDYANATHPUR (B	3282.77338300000	522.25940184091	257.78767452800	2.02592852	1949
	NEAR MAJHYAMPUR	495.60468500000	78.84619988636	333.85752664900	0.236167208	294

where, w = Specific weight of water, Q = Discharge,
S = Slope (hydraulic)

Stream power (used as a surrogate for the sum of the flow forces acting on a specific reach of stream bank over a designated time period) was related to bank ero sion rates. The stream power is proportional to the Bed slope, discharge, and Specific weight of water. The high stream power is the cause of river bank erosion. The slope variation is less but the water discharge of Bhagirathi River is high, so the stream power is another reason for bank erosion.

7.3. Brick Making

Due to the process of using alluvial soil for brick making, dig the soil from Bhagirathi river bank is the another cause of bank erosion. Some places are Giria, Jangipur, Natun Dear, Nashipur, Mehadipur (4 km from Berhampur to kandi rout), Berhampur, Hatinagar (Berhampur), Dhulian, Niswadbag, Madhyampur (near Beldanga) and Mahala etc.

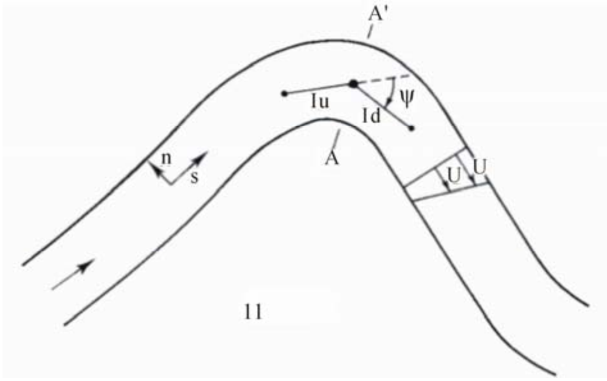


Figure 11. The adjacent upstream and downstream nodes.

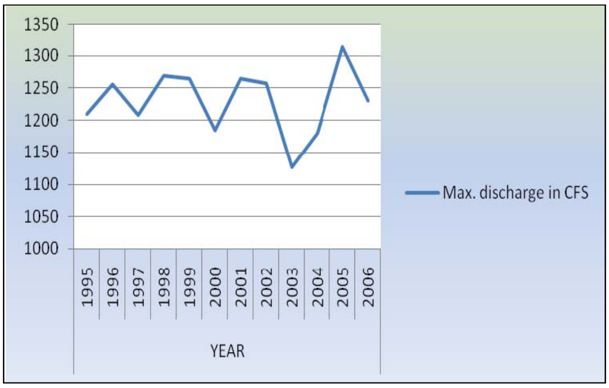


Figure 12. Maximum water discharge of feeder canal in CFS (Source: CPT).

Near about more than 200 brick making factories are influence on Bhagirathi River bank at Murshidabad District. One a day a brick factories dig approximately 12 to 16 trucks (11f *x* 6f *x* 2f) soil from the side of the river. Approximately 800 to 1000 bricks are prepared from per truck.

7.4. Slope

As the less variation in Hydraulic Slope (**Table 8**), it is not a main factor for the Bhagirathi bank erosion. After using the Equation (10) the hydraulic slope of the Bhagirathi river bed is calculated.

$$\text{Slope} = 2.09\left(\frac{M^{.86}}{Q^{.21}}\right)\ \text{feet/1000f} \qquad (10)\ [2]$$

where, M is Mean Particles Diameter, Q is Discharge. The mean Particles Diameter from Giriato Jangipur is 0. 144 mm, from Jangipur to Berhampur is 0.155 mm an d After Berhampur Particles Diameter is 0.209 mm.

7.5. Velocity

It is very difficult to observe the mean velocity of the river due to time constrains. Most probably the velocity

Figure 13. Soil map of murshidabad.

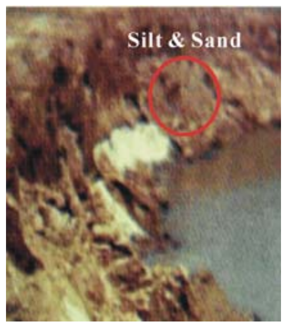


Figure 14a. Clay and sand.

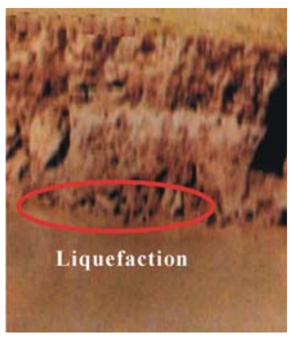


Figure 14b. The soil particles.

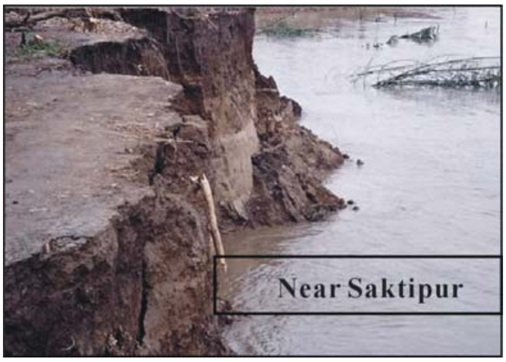


Figure 14. Field photo.

Year	SLOPE IN FEET/1000 FEET ($1x10^{-73}$)		
	Giria to Jangipur	Jangipur to Berhampur	After Berhampur
1995	1.95855	1.09973	1.60451
1996	1.94359	1.09133	1.59225
1997	1.95924	1.10012	1.60507
1998	1.93907	1.08879	1.58855
1999	1.94036	1.08952	1.58960
2000	1.96751	1.10476	1.61184
2001	1.94036	1.08952	1.58960
2002	1.94294	1.09097	1.59172
2003	1.98800	1.11627	1.62863
2004	1.96891	1.10555	1.61299
2005	1.92524	1.08103	1.57722
2006	1.95149	1.09577	1.59872

of river is very uniform in this stretch.

8. Management

The traditional bank protection works, concrete walls, cemented stone and brick, play a significant role in the modification of the hydraulic aspect of the discharge values and in the interference in the water dynamics of erosive and depositional phenomena both upstream and downstream.

- Trees with more condensed routs should be planted to protect the erosion by the side of the river bank.
- Not only that to prevent erosion temporarily, big stones should put into the nets and would be placed where erosion effect severely; especially where people inhabits closure to the river.
- As for as strong protection is concerned concrete (cemented stone) embankments may be made to prevent it. Especially in those areas where erosion effect relatively moderately way. To be more practical this methods may be used from Dear Balagachi to Baidyanathpur of Murshidabad District.
- More over the process of using alluvial soil for brick making from the side of the river should be controlled.
- Heavy water discharge is considered responsible for bank erosion. More discharge is the source of more power of stream and more stream power occurs more erosion in meandering river (Bhagirathi). If some Barrage are constructed to reduce discharge, stream power consequently will be reduced and it will be a sustainable method for it.
- By the cutting down Some canals (like feeder) from Bhagirathi River to another river and divide the water for agricultural land, associated people, irrigation, fisheries, and hydraulic structures, it will be reduced the water discharge and erosion.
- Methods that deflect flow away from a bank to avoid erosion is the another methods Bank Protection.

9. Conclusions

Remote sensing and GIS technology shows the great potentiality to study the shifting of the Bhagirathi River. It is observed from the toposheet of the year 1970 and image of 1977 (MSS), 1990 (TM), 2000 (ETM+) and 2006 (google image) a significant change of the river pattern. Due to fluctuation of water discharges from the Farakka Barrage through the feeder canal at Jangipur and also soil structures are the main cause of Bhagirathi River bank erosion (Field photo, **Figure 15**). Maximum erosion takes place at Dear Balagachi and after Baidyanathpur. A cut-off has take place at Baidyanathpur in 1984. It is found from the study that there is a possibility of natural meander cut-off at Dear Balagachi and near Majayampur. This study may be useful for future planning of land use, its associated people, irrigation, fisheries, and hydraulic structures.

10. References

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