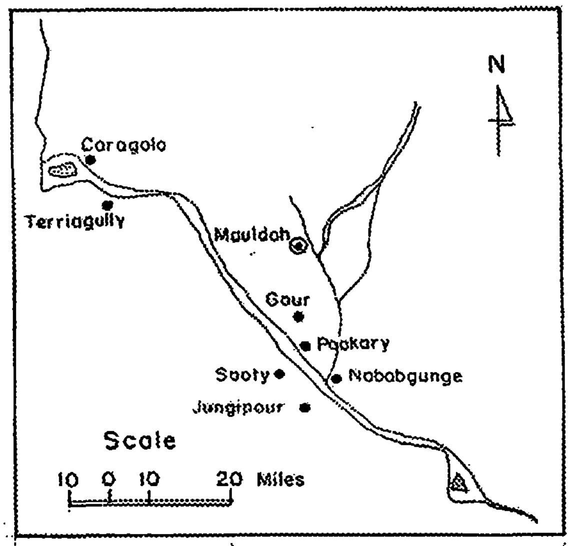
CHAPTER - III

Bank Erosion: Analysis of Causative Factors

3.1 Historical Perspectives

The river Ganga receives prolonged history of migration and shifting. For centruris, many people in the world have depended on mighty rivers for their livelihood.However, the river has been found migrating , sweeping and ultimately removing agricultural land and cities in their path (Gupta,& Philip,1989).Channel migration or channel changes are taken to include any change in river channel geometry within the context of the cross section, the pattern or network of a drainage basin (Gregon, 1977).To carry out the work mainly secondary sources were used and consultastios of the historical, offical, folkstories and diary records of Britishers were studied in a manner of cross verification and searching out the general concepts to establish the factfulness of the occurrences. *It is a try to say that the attitude of mighty rivers over their flood plains is an important casuative factor of bankline change through erosionMany a time these change detections are associated with flood incidents and earthquake activities.* Once the river used to flow alongside the Bengal's capital *Gauda*. Rennel stated that '*Gour* ,the ancient capital of Bengal stood on the old bank of the Ganges although its ruins are 4 or 5 miles from the present bank'*(fig.3.1).*

GANGA COURSE : 1781



Source: Published according to act of Perliament by J. Rennell Jan. 1st, 1781

Figure 3.1 Location of Gour city at the east of River Ganga during the end of 17th century.

This prove the river had always a tendency to swing towards west from the beginning to the middle of the 15th century.

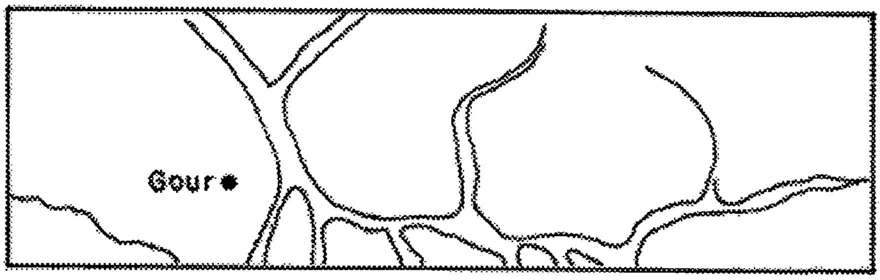
During 1700 to 1800 centuary Gour was situated at the east of Ganga but the scenario changed afterwards.

The numerous beels throughout the district are the direct and indirect result of fluvial action. From the appearance of these abandoned channels, it can be surmised that they were originally courses of very much larger rivers than the present streams (Sengupta, 1969).The same direct river action is found in the *diars* where the beels are depressions left by the Ganges as it has found successive new courses to the west. There is also a chain of beels situated in the low-laying marshy tract between the Mahannda river and the main road from Englishbazar to Gour. (Sengupta, 1969). Available records show that the main channel of the river in this reach is oscillating from left to right and again to left.

At present the river is experiencing the phase of leftward swing which started from the beginning of the last century engulfing large tracts of fertile lands.This has been caused by what may be described as indirect river action (Sengupta, 1969). A silt bearing river use to build its own bank over periods by depositing silt and formation of high level bank than the interior. Such process continuing for centuries, result into the formation of low lying and shallow interfluves in between the rivers, obviously in case of the mighly Ganga and its neighbouring Mahananda can have faced such morphology of interfluves.

It was estimated that probably after a great deluge or earth quake, the shallow basin part became the further westward channel of river Ganga and the process eventually affected the present attainment of the river Ganga hugging the western most part of the district away from *Gour* or *Gauda*.It is undoubted that a part of the mighty Ganges flowed southwards along the city's western wall. Consequently the level of the land along this old bank of the river is high; and it is probable that any flooding of the countryside areas further east was prevented by the rampart of *Gour* and further north by main road (Sengupta, 1969). This whole process took about 250 years starting from the beginning of 1500 century to the end of the 1650s to 1700 century. 'J. the Baros' in 1550 prepared his map where he showed the river Ganga was flowing further south of *Gobra* which issituated in Harishchandrapur

PoliceStation.Thus evidences prove that the flow of main Ganga was far off east than *Gour* and enventually *Gour* came to the bank of Ganga intermitently within this phase of prolonged shifting of the river Ganga. In the year 1561 the famous work of 'Gastaldi' also evident the location of river Ganga alongside the North eastern part of Gaur Dynasty (Mijanur Rahaman, A trimonthly bulletin).During 1500 to 1600 century Gour was situated at the west of Ganga *(fig.3.2),* just reverse to the *fig.3.1.*

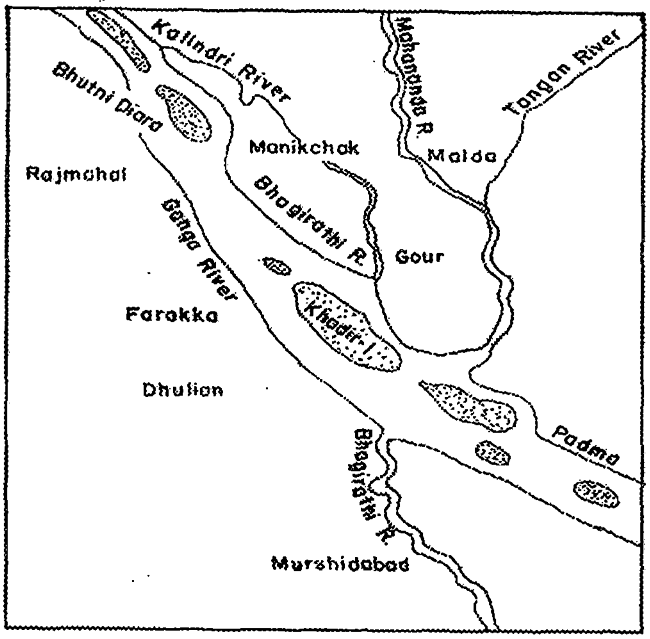


Source: Gastaldi's Map (1561) Gour and River Ganga at the North East Corner of Gour
Courtesy: Mizanur Rahaman & Abdus Samad

Figure 3.2 Location of Gour city at the west of River Ganga during middle of 15th century.

In 1595 'Irfan Habib' completed his 'An Atlas of the Mughal Empire' and there he showed the location of the river Ganga far away west to the Gaur, which indicated the shifting of the river almost like the beginning of 1900 century hugging the western boundary of the district *(fig.3.3).* Not only this, it also proved the volatile swinging of the river over periods.Such position existed more or less same upto 1922-23.Abdus Samad also supported the truth in his famous work *'My discovery of Ancient Gour at Kandran & its connected surroundings,* 1st and 2nd edition and he seriously carried out the outcome of the history of *'the nadia sahar in Malda,* meaning thereby the town of Nadia is in Malda.

Astonishingly during 1900 centuary the same situation has been found like the 1700 to 1800 centuary situation.Exponents belive that ,these changes of river morphology took a prolonged period of about 1150 years, perhaps starting from Gupta empire to the beginning of the last century. Actually such incidents were associated with high frequencies of flood like 1871, 1875, 1885, 1905, 1918, 1922, 1933, 1935, 1936, 1948, 1960 and so on.Reconstruction of historical informations prove that, before 1800 there were several examples of flood which were not recorded.

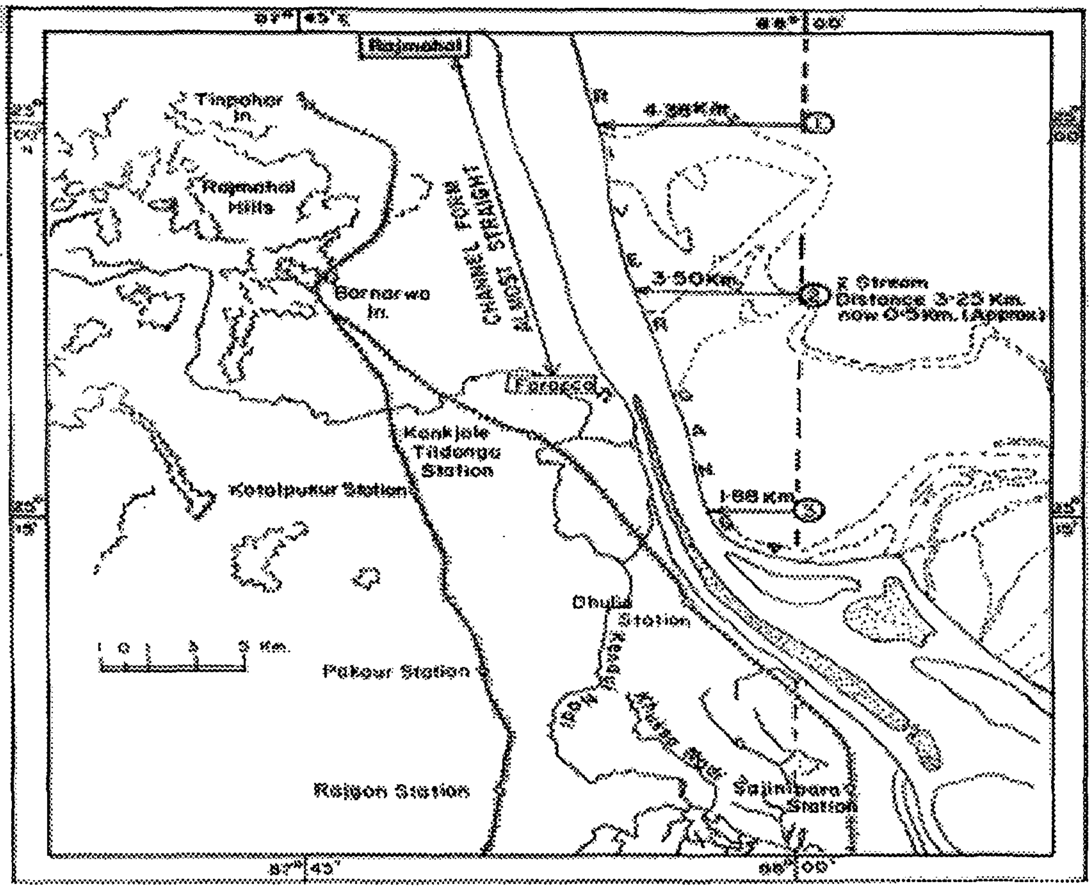


Source: Ghosh, 2004.

Figure 3.3 Ganga in a south-easterly direction during 19th Century (Gour at the east).

On the other hand occurrences of earthquakes of 1772, 1784, 1897, 1934 also created the probability of course change.Occurrences of flood in the last century should also be taken for consideration behind such immense river metamorphosis; like the flood of 1971, 1980, 1886, 1987, 1989, 1990, 1991, 1998, 2003, 2004 etc. which aggravated the intensity of bank side slumping and there by steady shifting. While viewing the past, it really becomes obvious to infer that the withdrawal phase of 2003 flood accelerated the dangerous lateral river piracy of Ganga and Pagla.

Actually the serpentine swinging of the river did not take rest for long reaching to the western most boundary line of the district; rather it started to swing again eastward from the beginning of the last century (1900 A.D.). The history of the last century regarding course shift was found also very much interesting.Survey maps of 1922-23 and 1936-37 showed almost straight channel like crow fly line between Rajmahal and Farakka*(Fig.3.4)*.Intricate examination of the survey displayed a number of successive crescent shaped abandoned waterbodies and obviously the crescent shaped pattern of differential settlement near left bank of Ganga at that time.



Source: Rennel's Survey 1765 & SOI, 1917, India
(LT: 24 00/23 45, 24 00/23 30 & LG: 89 30/89 00, 88 45/88 30)

Figure 3.4 Most straight course of Ganga during the beginning of the present Century between Rajmahal and Farakka.

The geometric orientation of the paleo loops and settlement lines are similar to that of eroding left bank line subsequent to 1922-23. The propensity of aligning loops joining and forming the *Maraganga* is still noticeable. Another reasoning fits in such a way that the interfluve line between the left bank line and differential settlement line is characterized by unconsolidated existence of sands and silts i.e. erescent shaped sand bars. The height of the old Ganga bank was 5.0-5.5 m which is the evidence of leeves of Ganga bank. Starting from 1930s to 1940s the river gradually moved to the right and in the process left succession of curve shaped loops.

3.2 Major Causative Factors

The following responsible factors have been considered behind the causation of Ganga River babk erosion.It has been divided into two parts:

3.2.1Natural

3.2.1.1 Lithology of Bengal Basin

The area of Ganga Brahmaputra basin is 1,50,000 Km^2. In a depressed synclinal shield region the accumulation of sand, silt and clay during a prolonged period of 70 lakh years such a basin was formed. Geological Annals reveal the history that Bengal delta is formed by a chain of fluvio-techtonic actions operating over the mio-geosyncline of the Bengal basin Stratigraphically,a section,of the upper Cretaceous limestone and calcareous shale overlies the upper Mesozoic basalt flows (Sarkar, 2004) and associated trap wash, granite wash rocks near Ghatal,Debgram and Jalangi deposited under brackish,marshy,estuarine lagoon (Biswas, 1963; Sengupta, 1966; Sarkar, 2004). Geological and sedimentological evidences sited near Jalangi show thick and freshwater sedimentation between two phases of Eocenal marine transgression and during that period of deluge the pre existing Bengal-self was replenished and reached to its final conFigureuration.During the intermittent period of late Miocene to Pliocene again south-eastward transgression took place under deltaic and shallow marine environments.Submerged condition prevailed for the long run of entire Pliestocene age. In the late Pliestocene the sea finally fall back and Bengal Basin was withdrawned from the submerged condition.Erosion then started followed by peneplanation of the entire Tertiary period in the Bengal basin. In the above diagram Umitsu has shown in the condition (d) the condition of the sea coast line demarking the last phase of Pliestocene withdrawal and extension of bengal Basin further southward resulting into increasing of the length of the River Ganga including the entire Ganga system and that provoked the river system for further hydro-dynamic adjustments *(fig.3.5)*.This actually resulted the rivers to attain more graded path of flow and consequently the River Ganga started curving its eastern bank taking the soft lithology of the alluvial soils.

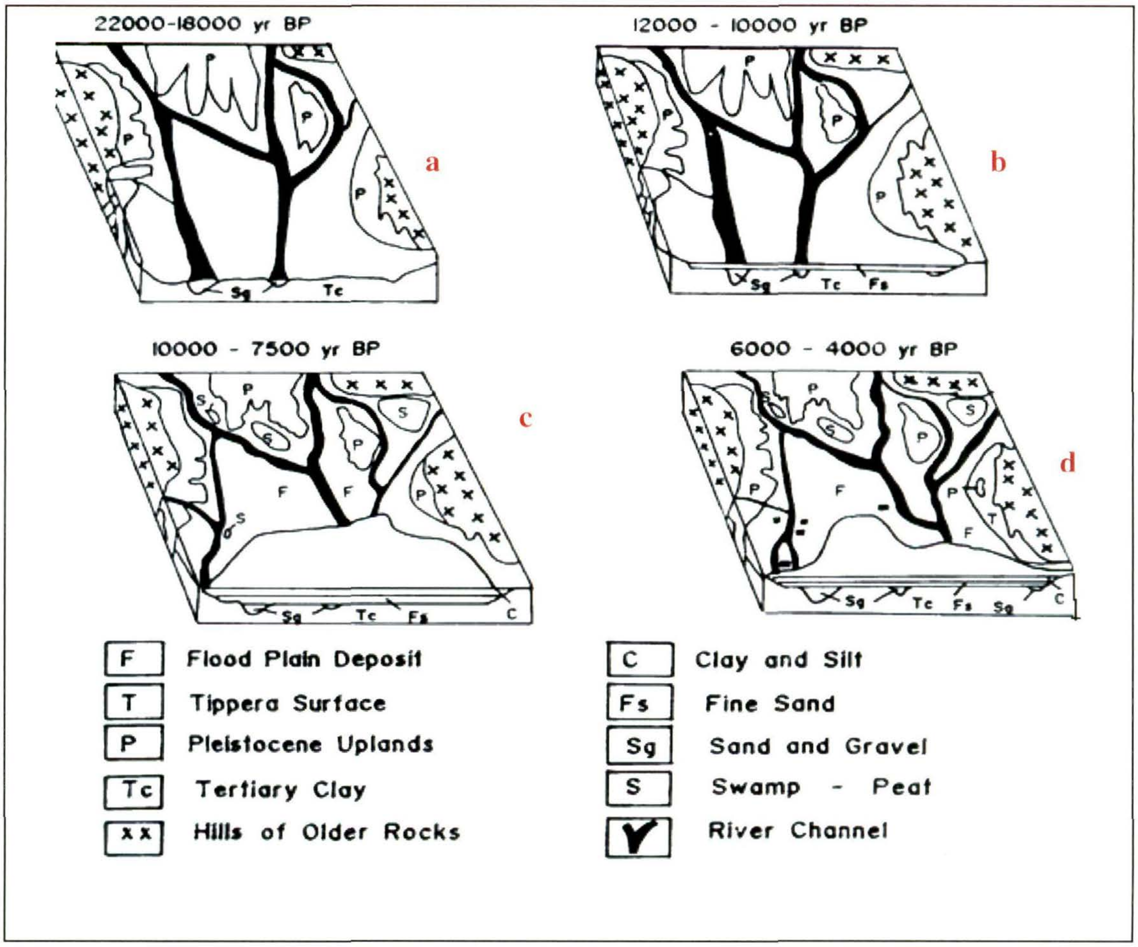


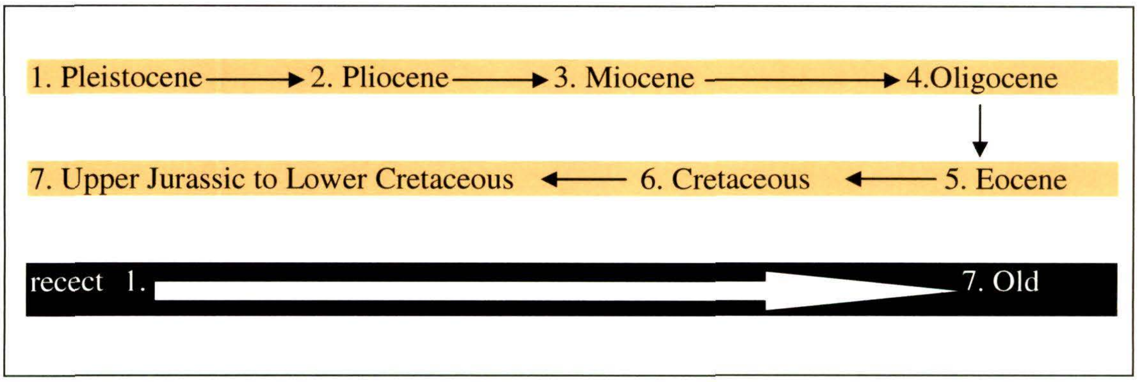
Figure 3.5 Stages of Development of Deltaic Plain of West Bengal and Bangladesh after Umitsu (1993).

In the late Holocene due to several deluges and unprecedented floods the entire basin was covered by the mantle of newer alluvium (Sarkar, 2004). From the lithological point of view generalization of country soil profile can be diversified with a fluvial deposition underlined by predestined Quarternary silt (Sarkar, 2004).

3.2.1.2 Geological history of formation of Bengal Basin

To the east of more or less the longitude **$87^0 00^{/}$E** is the great Indian shield which disappeares below a blanket of gangetic alluvium.The exposed part of the Archaean Shield,which boarders this extensive alluviated plains is marked by a number of intracratonic Gondwana basins along the Damodar river valley, a few exposure of early Tertiary age near Durgapur and Baripada and the late Mesozoic volcanics of the Rajmahal hills (Sengupta,1969).The Bengal plain is surrounded to the NE by Shillong Plateau and this has really continuation of basement complex with

Garo-Rajmahal Gap to the west and the Great Peninsular Decan shield of south and southeastern India through a shallow subsurface edge of Bengal synclinal basin.The eastern limit of the subsiding zone is demarcated by the Naga-Lusai Hills of cretaceous origin. Below the thin cover of Holocene alluvium in West Bengal, there is thick section of Cretaceous and Tertiary sediments lying on a basement of basalt lava flows presumably of the same age as the Rajmahal volcanics (Sengupta, 1969).In the western fringe of the Bengal basin the Archaean shield is traced below a thin veener of alluvium. In this zone below the alluvial blanket locations of domal and buried anticlines have been found after drilling of the subsurface layers.The following table is showing the geological ages of formations experienced over the Bengal basin as emphasized by Ramachandra Rao M.B and Sengupta S.N,1964.The statigraphy is as below:



The total thickness of the deposited sediments increases to the east and southeast (maximum thickness of 11,890 m in Bangladesh) Normal faults down-to the-basin is passing through the Jalangi, Debgram and West Ghatal. The Bengal self is diping very gently about 1.5^0 towards southeast.During early Cretaceous age lava flows over the foreland self of Bengal together with Shillong Plateau became embodied to form the base of the self with hard shields.In the late Cretaceous the subsidence of the self area was occurred when brakish to lagoonal deposits accumulated on the Bengal self (Sengupta, 1969) under open marine condition.Upto the middle of Eocene such submergence continued to the deeper parts of West Bnegal and Assam and experienced marine invasion (Biswas, 1963, Sengupta, 1969).In late Eocene, marine transgression continued on the stable self of Bengal and Shillong massif. Two different deposits of Bengal side self and Assam side self within the same syncline brought close to each other due to thrust tectonism i.e. compressional movements (Sengupta, 1969).

On either side of the Eocene hinges, in West Bengal two distinctly different types of rocks or contrasting lithological types took place.In post Eocene movements on the nummilitic limestone hinge traversed the whole Bengal Basin.During Oligocene great regression of the Eocene sea resulted due to elevation of the different parts of the basin.Over this prolong period only fresh water to estuarine deposits accumulated. Whereas shallow marine conditions went continuously in parts of the deeper basin. Major tectonic movements occurred over the whole of Bengal and Assam during the entire Miocene.Movements on the major north-east-south-west tending fault zones of Bengal basin caused rapid sinking of the deeper self and the geosynclinal parts of the basin resulting to marine transgression in the eastern part of the stable Bengal self (Sengupta, 1969).During the Pliocene most of the mobile belts were uplifted and widespread regression continued.From then not only esturine rather fluviatile conditions of deposition prevailed in most of West Bengal.At this period, Eastern Himalayas were thrusted southeast towards the present day upper Assam valley. In the early Pleistocene only the deeper parts of the Bengal Basin was found under shallow marine codition.In the late Pleistocene the marine transgression ultimately withdrawned from the Bengal Basin.During the whole Tertiary period peneplanation due to fluviatile actions continued and river borne Holocene alluvium made the mantle cover over the older or 'Bhangar' alluvium.The river action had a very fast down-cutting and following constant deposition by magestic rivers like Ganga, Brahmaputra etc.contributed their burdens to shape the front up of the basin estuary and further retreat of the old Tertiary sea which later on termed as Bay of Bengal and took place in reality. Till now the discussion is oriented towards the formation and ultimate make up cum shape up of the Bengal Basin. The relevance of the discussion lie in the background study of the lithology of the Bengal basin characterized by very loose, less compact and lower consolidation of Holocene sediments mainly for which magestic river like Ganga was offered very low the shear resistance from the bank soil compared to huge shear streeses offered by the impinging flow attacks of the river current consequenting upon vigorous bank slumping. On the other hand Rajmahal Hiills are offering tremendous resistance against river currents,and which is also creating reactions to the opposite bank i.e. left bank and for which the thalweg line is coverging more towards the eastern or main channel of the river.

3.2.1.3 Impact of Relief and General slope

The general slope of the district Malda is not more that 2^0.Mostly diaras have less than 2^0 slope amounting to river bed slope of 1 in 21,000 (Mazumder, 2001). Such a gentleness of slope allow stagnancy of channel water consequent upon very low velocity amounting to averagely 1.49-2.5 ms^{-1}, which results into excessive hydrostatic pressure on the channel walls and downfalling of the bankside walls collapsing into the river water.The general physiography of the district is from Northwest to southeast.The highest elevation of the district above sea level is 39.7 m at the place where the health centre at Pandua in the police station of Gajole is situated (Sengupta, 1969). South of Kalindri lies the most fertile and populous portion of the district. It is seamed throughout by old courses of the Ganges.The most striking natural feature is the continuous line of islands and accretions formed in the bed of the Ganges by its ever changing currents and Known as the Diara. Actually 'Diara' is the low bank of a river and 'Karara' is the high bank (Lambourn, 1918). By extension these terms are commonly used to mean land below and above flood level, respectively in the alluvium (Lambourn, 1918). Elevations ranging between 30 to 39 m above sea level are found in the police stations of Bamongola and Habibpur where it is little over 38m.The other places of the district varies in elevation between 23 to 54 m and 38 m at Kaliachak.The slope of the district is gradual as is proved by the meandering course taken by the rivers flowing through the district (Sengupta, 1969). There are no hills in the district unless a few elevated tracts in the Barind. Parts of these high lands have an elevation from 50 to 100 feet(30-40 m) above the level of the Ganges, and being frequently intersected by deep water-channels, stimulated the appearance of small hills.Near the lower parts of 'Diaras at the location of Farakka Barrage the contour values have been found having average ranges of 15-28 m according to SOI sheets, 1971. Such gentleness of the district is thus favourable for the stagnation of water in the channel and steady discharge in many-a-time is obstructed and for which water head in the channel is always high. General scenario show 20-22m water level in Manikchak,25-28m near Panchanandapur and few meters more near Farakka barrage.Downstream and upstream of Farakka Barrage there is always a gap of 2.0 to 2.5m. Such situation makes the river from Panchanandapur, Laskarpur to Farakka i.e. in the lower section out of the 76 km reach of the river in Malda, to be curve for holding high volume of water withstanding in the channel for more the time than is required.This consequent upon increment of cross section area by accelerated lateral erosion. For this reason in the eastern bank erosion is operative and on the other bank at the Jharkhand side alluviaton is operative and almost in every year it is continued because of the variation in bank erosion of the river Ganga.

3.2.1.4 Mechanical / Physical Properties of River Bank materials

Study of sample profiles and indepth on-field investigation in and around affected blocks of Malda displayed the following characteristics. 44.16% of grains are of medium size designated with 0.6-0.2mm of diameter, 50.66% are of fine size having diameter of 0.2-0.06mm and only 5.17% of grains are of coarse size in nature i.e. diametr of 0.06-0.02mm.On the other hand average void ratio of the soil was moderate to high i.e.30-35%.Level of density was found moderate to low and amounts to only 1.75 to 1.80 gm cc^{-1} and record of specific gravity was amounted to only 2.63-2.69 m See^{2-1} as given by CWC, 2003.Thus on- field analysis proves the excessive susceptibility of the soil to be eroded.Texture analysis also exhibits a sandy loam nature of the soil standing on the clay loam substratum*(table.3.1)*. For this reason where subterranean passageways undermines the clayey substratum the sandy top soil slumps down by river action easily.Not only that viscosity level was very poor and presence of average organic carbon was found as low as only 1.1%.On the other hand several sub processes accentuate the final outcome of deep erosivity like surface racking, shattering, scooping, undermining,massive block fall, gravity falling, fissuring and leached-routing etc.Saturation to collapsation due to unloaded super incumbent layer is also thus very much operative here (Field observation, 2003).A model profile containing 7 layers (not properly identified) exhibited the following properties. From the top to the bottom the upper two layers have 50-60% of sand but the 3^{rd} and 4^{th} layers have 75-95% of sand and the last 3 layers are characterized by 20-30% of sand but 30-50% of silt and clay. To be specific it was experienced in the field that the 3^{rd} and the 4^{th} layers (pedons) are facing the critical water table which in the form of impinge flow ebbs and is striking against the bank and erosion is taking place easily for which the overridden horizons have nothing but helplessly collapsing to the feet level of the bank.Here, three critical angles have been observed. At the top precipice slope amounting to about 89^0, Root bank slope amounting to 10-12^0 and

Remnant slope amounting to 30-35^0.Root scouring increases possibilities of collapse.Where as wall like precipice slope is prone to gravitational fall.Waterladden oversaturated bank soil at the top associated with deep rill and gully formations result into steady mud flowage culminating into block failure for the verticle and horizontal fractures.Steady infiltration and rapid downward percolation during the heavy rains result into areal collapse.Thus the entire bankline starting from Manikchak to Farakka is affected by heavy attacks of erosion due to its unconsolidated and loose constituent materials.

Table 3.1 Physical properties of river bank and deposited bed materials.

Sl. No.	**Sample site**	**Density (gm/cc)**	**Specific gravity (gm cc^{-1})**	**Void Ratio (%)**	**Grain size in percentage**				
					Coarse sand (2.0-0.60 mm)	**Medium sand (0.60-0.2 mm)**	**Fine sand (0.2-0.06 mm)**	**Coarse silt (0.06-0.02 mm)**	**Coarse sand (2.0-0.6 mm)**
1.	A	Between 1.75 to 1.80	Between 2.63 to 2.69	Between 30-35%	-	29	70	1	100%
2	B				-	44	56	-	100%
3	C				-	52	48	-	100%
4	D				-	16	69	15	100%
5	E				-	48	47	5	100%
6	F				-	76	14	10	100%

Source: I & W.West Bengal, 2004.

3.2.1.5 River hydraulics: channel water head, potential and kinetic energy

Total energy of water in any stream line passing through a channel section may be expressed as the total head of water, which is equal to the sum of the elevation of the stream line above a datum, the pressure head and the velocity head.Considering the profile of a gradually varied flow in the elementary length 'dx' of an open channel. the total head above the datum at the upstream section is

$$\mathbf{H = z_d + y + \alpha\, v^2/2g'}$$

Where, H = total head in m, local arbitary dalum

Z=datum height (m) =10.00m(local datum) near Panchanandapur

y= depth of water (m)

α = energy co-efficient (α = 01)

v = mean velocity of the section (m s^{-1})

g = acceleration due to gravity (g in m S$^{2-1}$)

A model case study on the computation of water head based on secondary data and mathematical calculations at 5 locations in and around Panchanandapur was carried out to understand the water head pressure along the poorly non-cohesive bank materials *(table.3.2).*

Table 3.2 Bank Cross section-wise channel properties for water Head (m) calculation.

Identity of the bank cross section	Z_d(m)	y(m)	α	V(m s^{-1})	g (m S^{2-1})	H (m)
Bank Cross section along D/s 01	21.96	10.00	01	0.396	9.785	22.488
Bank Cross section along D/s 02	10.00	12.98	01	0.43	9.788	22.99
Bank Bank Cross section along D/s 03	10.00	13.64	01	0.44	9.789	23.65
Bank Cross section along D/s 04	10.00	12.42	01	0.44	9.800	22.51
Bank Cross section along D/S 05	10.00	14.34	01	0.49	9.810	24.35
Thus,MeanHead for the all bank sections = 23.20 m						

Source: Compiled Data,2005.

Now in the following table a comparative statement of water head level and gross water guage level irrespective of time reference to understand the general situation has been presented*(table.3.3).*

Table 3.3 Site-wise statements of channel Water Head (m).

Site	Water Head (m)	Mean Head	Total length of the reach	Per km share of water head
Manikchak	23.09	22.75 m	76 km	0.30m
Panchanadapur	23.20			
Farakka	21.962			

Source: Compiled Data.

Thus explaining the situation is really to discuss something critical. Taking the case of Panchanandapur, it can be inferred that the pressure of water head in comparison to average cross section area is really an overburden here. The average cross section area along the 5 bank cross sections at panchanandapur is 9924.90 sq.m (9.93 sq. km). Thus one sq.m area receives water head pressure of 2.29 m which is itself a power equals to thousands of hammering against the loose sand-silt composition of the bank soil.The exertion of water head pressure along the banks can easily exhaust the water saturated loose constituent materials consequent upon steady gravity fall and avalanching of serial blocks of bank soil associated with fissures and gullies. On the other hand the associative factor of hydraulic water pressure is the stagnancy of high water volume for more than required time in the channel.Similarly along these cross sections the average velocity of water (v) has been computed very low to negligible amounting to 0.396-0.949 m s^{-1}.Thus it is quite evident that discharge over the unit cross section area is of very low magnitude than that of expectation.Such a situation is actually aggravating the chances of hydraulic pressure in the channel and consequent bank slumping specially at the end of wet season to almost all the seasons of the year.

Potential Energy

The power of the river is defined as the power of erosion, transportation and deposition **(Rauf,2006)**.Whenever sources of water increases and are debouched in the channel, velocity of the river also increases and thereby the strength of the river increases from normal to critical attitudes.Thus river flow is directly related to the river. Static energy transfers to dynamic energy.All such theoretical letting will be judged in the next part of discussion with the mighty river Ganga and estimations of power to erode its left bank will be taken up.

Potential energy is equal to the weight of water times the head, or difference in elevation of two points between which the energy is being calculated (Moriswa, 1968).

Now EP = WZ = M.g.h

where, EP = Potential energy

W = weight of the fluid.

Z = elevation difference(m)

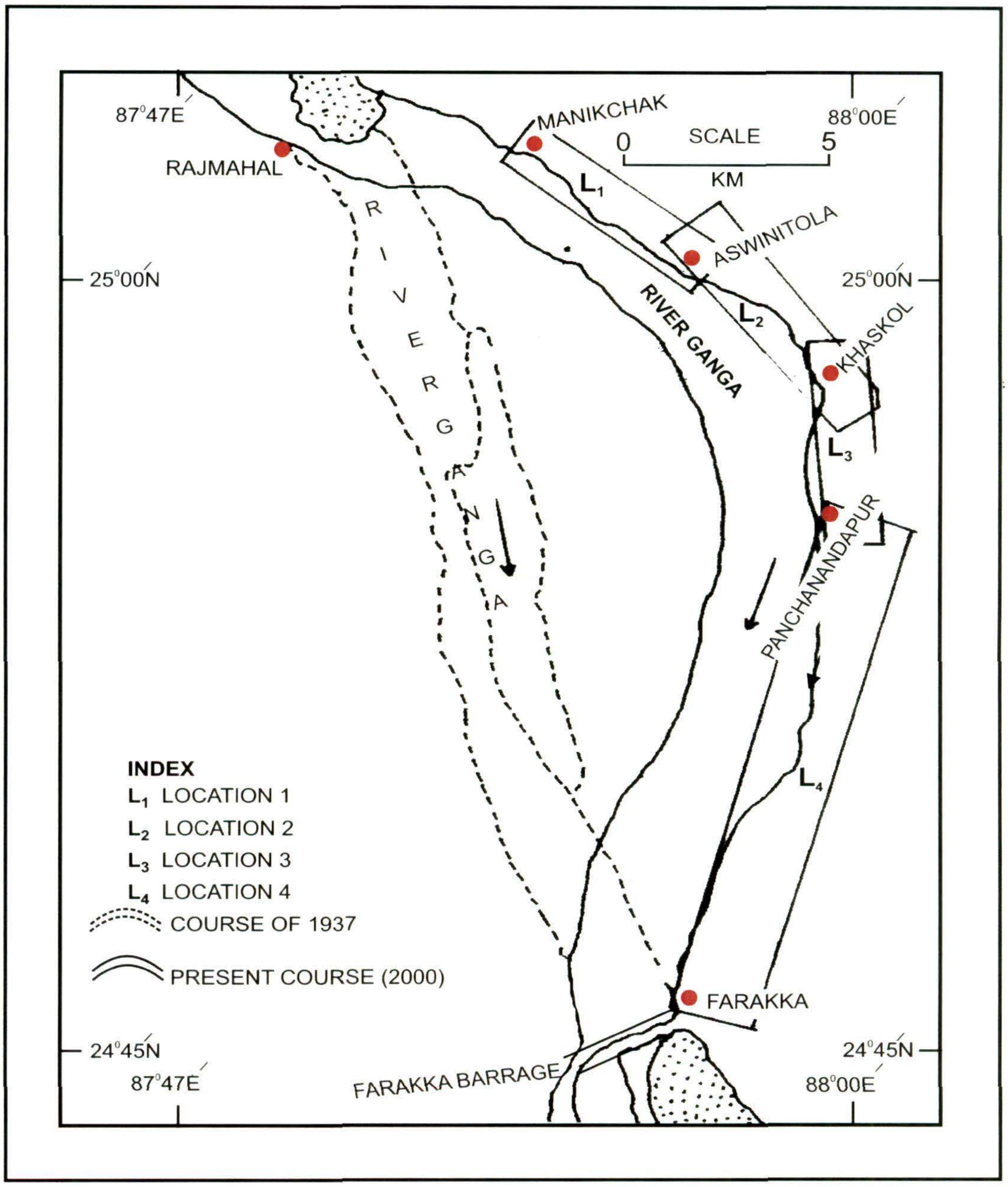
h= equivalent to value of Z

g =gravity (9.8 m s^{2-1}: Normal)

M=mass of the fluid

study of river energy on the basis of data received from model studies(CWPRS with I nd W Deptt., Govt. of W.B) in simplified form for the four locations has been considered here. The study by the author is purely ***a model study*** approach to understand the nature of river energy (theoretical) in this section only *(fig.3.6)* as mentioned below*(table.3.4)*.

LOCATION OF FOUR IDENTIFIED SUB REACHES FOR RIVER ENERGY ANALYSIS



[Based on Rudra, 2000]

Figure 3.6 Sub-Reach wise Location of Areas for the Assessment of River Energy.

Table 3.4 Sub-Reach–wise Geographical Identity of Locations.

Sub-Reach	**Geographical Identity**
Location 1	Manikchak to Aswinitola
Location 2	Aswinitola to Khaskol
Location 3	Khaskol to Panchanandapur
Location 4	Panchanandapur to Farakka

Source: Compiled Data

Note: Few Figureures below are data based, few are graphical calculations and few have been mathematically constructed through emperical formulii.

The results of mathematical calculations are as below*(table.3.5)*.

Table 3.5 Sub-Reach –wise statement of calculated Potential Energy.

Location	**Potential Energy Equation**	**Q*[1]** $m^3\ sec^{-1}$	**M*[2]** **($Q_1 x D_1$)**	**D*[3]** **gm / cc**	**h*[4]** **m**	**$g^{//}$*5** **m Sec^{2-1}**	**EP** **J S^{-1}*[6]**	**% of Potential Energy**
Location 1	$EPL = M.\ g^{//}.\ h$	17,000	Mass is an expression of density multiplied by discharge	1.58	1.3	9.770	34, 11, 48,860	**(4.41%)**
Location 2		28,000		1.62	1.8	9.780	79,85,17,440	**(10.45 %)**
Location 3		45,000		1.75	1.5	9.785	115,58,53,125	**(15.07 %)**
Location 4		76,500		1.80	4.0	9.788	539,12,30,400	**(70.07 %)**

*[1]discharge of water *[2]Density of water *[3]height difference *[5] Site specific gravity
*[6]Joule per second

Note: Discharge data has been simplified upto closest rounded off

Calculation for Gravity has been done as follows:

Here (i) $g^{/} = (1 - 2h / r)$

Here, h = height from sea level

r = Average Radius of the earth (In M.K.S system: r = 64,00,000 m)

g = Gravity= 9.8 m s^{2-1} (Average ;calculated over 45^0 North and South latitude)

(ii) Site specific calculation

$g^{//} = g^{/} (1 - {}^{1}/_{288} \cdot \cos^2 \alpha)$

where, α = Latitude

g = 9.8 m sec^{2-1} (Duari & Majumder,2007)

Now sector wise analysis reveals that, out of the total potential energy; within the entire reach location1 is receiving **4.44%**; **10.54%** is present within the location 2, **10.07%** is found within the location3 sub reach where as **70.07%** is within the location 4 sub-reach.The total cumulative percentage of potential energy was found exerting on the left bank between Khaskol-Panchanandapur reach.Thus tremendous head water pressure is predominating at and adjacent to Panchanandapur & Khaskol areas up to Farakka with slope as low as 1:21,000 and average velocity of only 1.93 m sec^{-1}*(table.3.6)*.Under this present condition the bank side water depth adjacent to above said areas is 20 m (+) below the pond level, whereas the average bank height above the pond level is 3 m (+). So the average 23 m standing bank almost like a wall or a precipice & composed of loose sand-silt lithology is highly susceptible to in-channel slumping mainly by liquefaction, bank-side fluting and block wasting part by part.The following *tables 3.6 and 3.7* present a very critical velocity condition in the River Ganga during torrential river regimes(peak season).

Table3.6 Velocities in m s^{-1} near the eroding left bank between Khaskol & Panchanandapur.

Velocity in m s^{-1}

Discharge m^3/sec	Location 1		Location 2		Location 3		Location 4	
	Along bank	100m away	Along bank	100m away	Along bank	100m away	Along bank	100m away
17,000	1.49	1.35	1.12	1.35	1.27	1.60	0.97	1.42
28,000	1.79	1.62	1.20	1.20	1.35	1.27	1.13	0.97
45,000	1.93	1.71	1.20	1.20	0.97	1.13	0.63	0.62
76,500	5.19	4.71	2.53	3.69	5.22	2.85	1.65	2.28
Total-1,67,500	2.6	2.36	1.51	1.86	2.21	1.71	1.01	1.32

Source: Compiled by calculation and field data.

Note: Discharge data has been simplified upto closest rounded off

Table 3.7 Velocity distribution at and far of bank.

velocity in m s^{-1}

Locations	Av. Velocity along the bank (4 spots for one location)				Mean velocity	Av. Velocity 100 m away from the bank				Mean velocity	Grand Mean
1	1.49	1.12	1.27	0.97	**1.21**	1.35	1.35	1.60	1.42	**1.43**	**1.32**
2	1.79	1.20	1.35	1.13	**1.37**	1.62	1.20	1.27	0.97	**1.27**	**1.32**
3	1.93	1.20	0.97	0.63	**1.18**	1.71	1.20	1.13	0.62	**1.17**	**1.18**
4	2.19	2.53	2.25	1.65	**2.16**	1.74	1.69	1.85	1.28	**1.64**	**1.90**

Source: Compiled by calculation and field data.

Kinetic Energy

Similarly computation of kinetic energy will also validate the cause analysis motive. It is that energy which is attained by the river in response to the down slope movement of the mass of the liquid governed by the factor of mass, amount of gravity imposed & angle of displacement over the bed of the channel i.e. magnitude of slope. According to Moriswa, 1968; it is equal to one half the mass of liquid multiplied by times the square of the velocity at which the water is moving. It is accelerated with the increment of bed slope i.e. inclination of the river bed down slope.

Thus $E_k = {}^1/_2\, mv^2$

where, E_k = kinetic energy

m = mass of water

v = Velocity of the liquid

Here attempts have been made to compute the kinetic energy starting from the upstream of the location one to the downstream part of location four.

$\boldsymbol{E_k = ½. Mv^2}$, thus applying the formula

M = (Q x D) = mass of the fluid

v = mean velocity.

Here location wise computations are as below (Ref:Table 3.6 and 3.7):

L_1 = 4, 53, 10,624 Js^{-1}

L_2 = 7, 98, 51,021 Js^{-1}

L_3 = 11, 00, 99,815 Js^{-1}

L_4 = 49,86,50,022 Js^{-1}

Sum of L_1,L_2,L_3,L_4 = **73,39,11,482** Js^{-1}

Now E_k = **73,39,11,482** /2

= **36,69,55,741 Js^{-1}**

In a comparative sense of discussion it is being evident that the average potential energy for the total reach i.e. the sum of values of potential energy of the sub reaches starting from location 1 to location 4 is **7,68,67,49,825** Js^{-1}, whereas the amount of kinetic energy for that entire reach is **36,69,55,741** Js^{-1}. Thus potential energy is more dominating than kinetic. As because of dominance of potential energy compared to kinetic energy, water stagnancy and resultant hydraulic pressure against the almost wall like concave inner bank within the channel is contributing regular steady pressure.On the other hand, the bank is composed of alluvial lithology mainly excessive of sand & silt than clay with standing wall like morphology*(table.3.8)*.Thus liquidification of over saturated bank results into slumping, cavitation, rotational slip, subsurface passage way, areal collapse etc.

Table 3.8 Bank Height character along the left bank of River Ganga.

Site	Bank height (m)				Av. Bank slope	
	Spot 1	Spot 2	Spot 3	Spot 4		
Panchanandapur (D/S)	1.80	1.75	1.55	2.00	1in 0.97	Steep wall like
Sakullapur	1.50	1.45	2.00	2.10	1in 0.95	Steep concave slip on side
Mohonpur	1.60	1.75	2.00	1.40	1in 0.89	Steep and very concave
Aswinitola	1.75	2.15	2.10	1.50	1in 0.78	Prcipice like
Domhat	2.00	2.20	1.75	2.30	1in 0.95	Meander bend arm & wall like
Manikchak (U/S)	1.50	1.71	1.55	1.40	1in 0.94	Exposed wall like form
Mean	=1.67	=1.84	= 1.83	= 1.78	in 0.91	Wall like erosive bank

U/S = upstream; D/S = Downstream

Source: On Field compiled data(June,2006).

According to the above table the average height of the left bank is within 1 to 3 m upstanding from the water table and study of 30 soil samples display that from the top to the average depth of 1.48 m or 1.5m there is almost no cohesive sand piled with almost precipitous bank side slope having angular position of the slope is 1 in 0.80 to 1 in 0.95.Thus stormy and heavy blow of impinge waves and secondary current ebbs due to variation of density and viscosity of river water,use to blow in such a way that bank soil fragmentation occurs vigorously.

On the basis of the distribution of slope,as in the following table, the sub-reaches of high erosive banks have been discussed.Vulnerability is analyzed here mainly on the basis of slope angles.For analysis point of view, the researcher has subdivided the total 76km reach into 5 sub reaches. Of which Panchanandapur – Sakullapur reach is characterized by slope of 1 in 0.736 which is really vulnerable to excessive gravity fall and avalanching phases with downfall, block glide and step wise sliding. Similarly Sakullapur-Khaskol sub reach is receiving the slope of 1 in 0.9952 meaning thereby very much susceptible to further erosin.Moynapur Domhat and Domhat-Manikchak at the upstream of the study reach are feauted with slope 1 in 0.9927 and 1 in 0.9930 respectively.Thus erosivity and erodibility ratio is far high from average slope angels.Only the Panchanandapur-Sakullapur reach as per present 'on-field' observations have some protective disposition which was highly susceptible during flood 1998-2000 and upto 2005. The hydrological mechanisms within the Channel is quite interesting. There is already formed a typical *meander loop* between the two districts Malda and Murshidabad keeping Farakka barrge as a nodal point in between this reach almost like the 'S' form.Actually Malda district is located on the outer side of the upstream meander. On the basis of the section study from authentic sources a schematic view was produced (not to scale) of the meandering Ganga (Mazumder,2001).There is a production of the secondary current due to centrifugal effect within the channel which is responsible for erosion of the outer bank and deposition of sediments on the inner bank (Mazumder, 2001).In fact the master flow when strikes the meander curvature of an almost wall like vertical bank, a steady shear stress is exerted over there and circulation of revolving or whirling water causes secondary currents. As much the outer bank starts to erode, curvature of the stream increases and the centrifugal effect also increases further development of secondary currents at greater depths consequent upon huge shear stresses and unexceptional erosion on the outer banks side of the river over the country rock. It is due to this process of continuing erosion of the outer side and sedimentation of the inner bank that the stream goes on moving outward and depositing sediment in the inner bank (Mazumder, 2001).As a result the thalweg (line joining the deepest points on the wetted perimeter of the crosses section) becomes to be very close to the outer bank and very distant from the inner bank as evident during section study, it is 200m.Thus the main flow with an averages velocity of 1.8 m Sec^{-1} and carrying of heavily viscous water exerts tremendous water pressure with a mean flow of 34,000 cumec and bed slope of 1 in 21,000 (Mazumdar, 2001; Valentine, 1992). Any banks can't be protected with embankment pitching and spurs when there is a deep scour depth near the bank. Fine sand-silt soils on which the embankment and spurs are built have extremely poor shear strength.Thus the embankments and the spurs both parallel and transverse are threatened by the shear stresses governed by flow depth and resulting into collapsing of the already scoured left bank affected by vigorous cavitation. Not only that the pitched head of the long spurs to deflect the stormy turbulence of the master flow from left to right bank i.e.Malda side to Jharkhand side becomes ineffective. Spurs themselves are likely to be washed out and their performance may not be expected (Kulkarni, 1999 and Mazumder, 2001). For example, Koshi Project Authority had constructed 364 spurs to save the marginal embankments. But the river Koshi is still breaching its banks either left or right almost every year.Another important thing is to understand the lifestyle of a majestic river in unconsolidated alluvium and contemporary resulting actions of fluvial origin. Streams do more than shift sediment by repeated scour and fill along the bed. They actively erode by (Butzer, 1976).

a) Channel deepening or by down cutting of the stream bed,

b) Channel widening through bank curving or undercutting

c) Channel extension i.e. head ward regressive erosion by streams and gullies

The erosion and readjustment of the channel is of two basic types in the case of River Ganga. Firstly, the valley floor over the plains of Bengal consists of river laden sediments of alluvium where the river shifts her channel and readjusts her bed by erosion and deposition. Long duration of deluge really accelerate the situation of abandonment of old course. As new channel is formed, the older channel is abandoned and filled, or as one bank of the river under meander geometry collapses, the river shifts in that direction and accretion follows on the opposite bank. Such erosion in alluvium is fundamental in the development of alluvial plains, being a mechanism, whereby the Ganga makes short or long term adjustments. Secondly, streams cut their way into upland where they usually erode into compact rocks and can transport their burden up to low reaches because of adequate slope at the upstream. Thus the mechanism and rates of erosion in bed rock are different and the ultimate effect is the sculpture of the interfluves; actually what was made by the same river during last migration and was abandoned. In Ganga basin in Malda the interfluve of Ganga-Pagla River as well Ganga-Pagla-Kalindri is highly threatening after any forth coming deluge in future. Cutting in the established channel of Ganga involves bed erosion, bank undermining, bank collapse, etc. to readjust and make possible to area of the cross section for increased volume of water having been obstructed at Farakka Barrage. Erosion of the alluvium on the river bed involves lifting and pushing of loose particles, particularly by turbulent water. Any cementing matrix in older alluvium under the bed or in the river is partly dissolved and individual are loosened by mechanical wear. Bank collapse due to undercut and resulting cavitations also play role together or sometimes separately. At some critical angle the bank slope become unstable, and the upper parts of the bank falls in or slide down, producing a gentle slope until undermining begins. Down pouring into the river, location of transverse spurs also play a vital role. Actually the iron weir and concrete and stony structures at discontinuous dispositions save the bank at distant locations, but in between the spurs, location of cavities develop incipient Gullies. The loose sand – silt composition attacked by diverted & whirling strikes of impinging ebbs make wounds creating crescent cavities *(table 3.9)* of 10-15 m in length. The following table is showing location-wise cavity formations.

Table 3.9 Spot wise cavity lengths

Location	Spot 1	Spot 2	Spot 3	Mean Length (m)
Panchanandapur	20.12	15.00	20.14	18.42
Sakullapur	12.00	18.21	10.12	13.44
Mohonpur	15.10	10.17	12.00	12.42
Aswinitola	15.63	15.00	13.50	14.71
Domhat	17.47	21.00	21.10	19.86
Manikchak	3.02	5.6	5.41	4.68

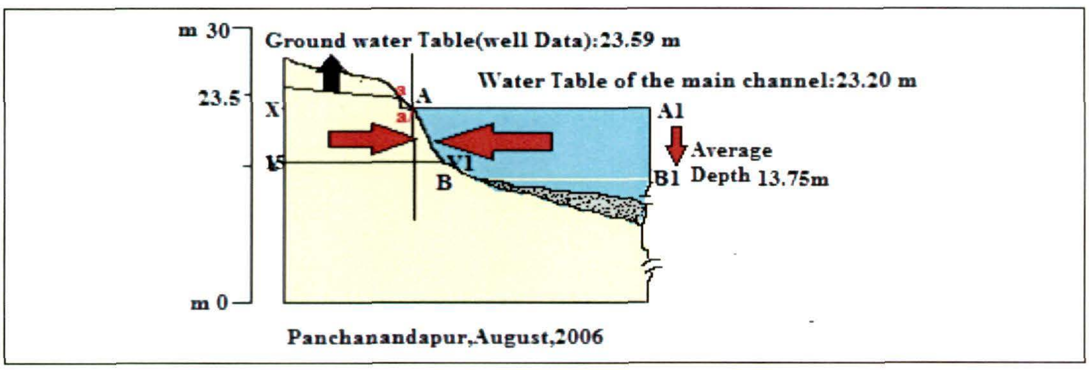
Source: Field investigation, July, 2009. Cavity Length in m

The most wounded cavities along susceptible banks have been found at Domhat and Panchanandapur having average length of cavity crescents of 19.86 m & 18.42 m respectively. In case of river Ganga, bank collapse is also aided by groundwater seepage or effluent seepage towards the opening of the flute mouth on the bank walls from sub surface origin. Of course such sub-surface seepage flutes determine the disintegration and lower cohesion of already sandy loose constituents of the bank. From July to September, these are full of water but in dry season these hollows collapse and downfall certainly creating disintegration cum slumping of the bank-side soil. Such a situation is aided by scouring and splash-scouring of raindrop erosion during monsoon months of the year.

Channels maintain in the riverine plain areas, steep banks and deep scour depths.However silty bank loose their cohessiveness as they become saturated at times of high water; as long as the water level remains high in channel and hydrostatic pressure may support the bank as the groundwater table remain almost at the same level. The similar water pressure in the channel and from within the ground water table make the bank stationary and time being stable. As the in-channel level drops down after wet season there is imbalance of channel's water table and the ground water table, the bank suddenly becomes unstable because of heavy ground water pressure and erosion in the form of block to block slumping. On the other hand, loose sands and silts tend to fall into a stream, maintaining steep unstable banks. Erosion is rapid and great quantities of bed load becomes immediately available.This favours channel widening instead of channel deepening. So that broad shallow channels are formed which use to aggravate the formation of in-channel bars and shoals at the slip-off side. Excessive bank slumping with the aid of water saturated block collapsation along bank lines is the main reason of bank erosion in Malda consequent upon river course changes as revealed in the studies of I & W, Govt.West Bengal, 2004.

Reduction of cross section area and formation of in-channel shoals initiate the development of cutting of new channesl over the alluvium.Gullies are extended during period of rains, when surface run off pours into a drainage line undercutting the head and incising the floor. Overflow channels and bifurcation can be accelerated by rilling and gullying, when water spills over an unbreached body of alluvium. A gully forms where the water pluges down and cuts back until a major channel has been croded. Thus development of gullies has also affected and has accelerated the problem upto an alarming situation.

During the wet season there is a proportional balance between the in channel water table and the subsurface ground water table. But the astonishing fact is that during the monsoon withdrawal period the in channel water table drops down fast than the subsurface ground water,and which results into channelward hydrological pressure and bank slumps readily *(fig.3.7)*.



Explanation: XA=Ground water table in wet season,YY1=Ground water table in dry seasonAA1= channel water table in wet season,BB1=channel water table in dry season, Y1B=Part to be attacked for hydrostatic instability,a-a/=Gap Height of two water tables(0.39 m).

Figure.3.7 Diagramatic presentation of Ground water table and channel water table at Panchananmdapur.

3.2.2 Anthropogenic

3.2.2.1 Over Population of Bhutni Diara and Duani Charland

`Keeping in view the socio-economic strata of the erosion affected areas, population pressure at Bhutni–Diara is another important reason of bank erosion.The total population of the district is 3,290,468 (as per Census 2001) which has been grown from 2,537,032 in 1991 i.e. a growth of 653,128 persons within a span of 10 years, which is indicative of excessive surface pavement.In long past bank erosion was a natural threat unlike in 1970s and 1960s but settled areas were not found at the close proximity of the bank lines. In 1922-23 the differential settlement line was found along the old courses of Ganga which have now been abandoned as quoted by I & W, 2004. The total area share of Bhutni Diara is about 13,043.99 hectare and the total population of the circular island was 47,173 in 2001 and 47,904 in 1991*(table 3.10)*. A reduction of 831 persons has been found from 1991 to 2001 which is an indication of recurrent flood and bank erosion. The population pressure in 2009 was almost 60,000 persons and extra addition of more victimized nature created refugees are about to 20,000 at the Bhutni Diara. Thus a gross population of about 80,000 in Bhutni and about 39,000 in Duania char adjacent to Bhutni is the present demographic scenario of this part of land. The most important information is that, the total length of the circuit embankment is 27.6 km having only two sluice gates to debouch the excess rain water which is insufficient to steady discharge of rainwater during heavy and incessant rains. Thus during the entire wet season the island becomes seasonal wetland and water logging for temporary periods create heavy inside pressure over the embankment and drops down its strength against breaching. It is rare that technology can over dominate the nature and natural process. These two charlands have been created by the river herself and were subjected to occassional flooding by spill water during monsoon months. But after the construction of th 'ring bundh' or circuit embankment the natural system has been disrupted consequent upon heavy pressure over the embankment from both inner and outer sides. This results into striking of the impinging river flows to be diverted and to attack the opposite side i.e. the eastern side bank of the river resulting into heavy seasonal slumping alongside for about 15 km starting from Manikchak to Domhat-Maynapour reach. The Fulahar Ganga-reach that is the eastern part of the circularity of Bhutni Diara is because of that, going to be much decaying for about many years and the western branch of the Ganga which is positioned to an acute angle striking directly Manikchak-Domhat reach whereas the debouchment site of the Fulahar Ganga is comparatively diverting from the Manikchak-Domhat reach. This is leading to the instanteneous water supply through trunk flow to the eastern bank and is resulting more erodibility to the already soft alluvium bank.

The impact of bank erosion has also been focussed on the population status of the islands. From 1991 to 2001 the population growth rate is 20.48% which is really for the building up of the temporary residential quarters of the shifted victims or hazard refugees, on the other hand, on the basis of net reduction estimation; about 8.11% population in 2001 compared to 1991 have left their houses from shibtola, Jagannath tola, Rajkumartola areas at the western part of the embankment and Kalitola-shankartola at the eastern part of the island due to erosion of Fulahar Ganga.

Table 3.10 Changing Population Scenario of Bhutni-Diara.

Sl. No.	Mouzas	JL. No.	Area (ha)	Population		Population Differential for 10 years
				2001	1991	
1	Gadai	1	1474.28	2,469	1,637	+832
2	Keserpur	2	685.43	1,082	949	+133
3	Uttar Chandipur	3	583.56	7,035	6,517	+518
4	Chandipur	30	1219.74	Deluviated	10,129	-
5	Chandipur Mal	4	1884.60	4,629	2,928	-1,701
6	Paschim Chandipur	5	807.76	6,761	4,862	+1,899
7	Harachandrapur	6	360.98	2,079	247	+1,832
8	NaoBararjaidir	7	190.20	4,648	4,118	+530
9	Suksena	8	654.57	5,155	4,836	+319
10	Dergram	9	91.12	Uninhabited	Uninhabited	-
11	Rambari	10	656.81	Uninhabited	Uninhabited	-
12	Sobhanathpur	11	113.49	353	1,450	-1,037
13	Hiranandapur	12	624.84	215	387	-172
14	Masha	13	323.75	Uninhabited	Uninhabited	-
15	Bagdukra1	14				
16	Bagdukra2	15	664.90	1,547	1,475	+72
17	Samastipur	16	244.43	Uninhabited	Uninhabited	-
18	Sohapur	17	190.20	Uninhabited	Uninhabited	-x
19	Chandipur Tafir	18	278.83	2,045	2,823	-778
20	Dakshin Chandipur1	19	668.95	5,014	3,586	+1,428
21	Duani Tafir	20	612.29	42	240	-198
22	Paschim Narayanpur	21	712.66	4,099	1,720	+2,379
	Total		13,043.99	**2001:47,173** 1991:47,904		

Source: Revenue Map,1931 and Census Abstracts1991 and 200147,904.

3.2.2.2 Role of embankments and spurs

Till 1931 the reach of the river was more or less straight between Rajmahal and Farakka (SOI sheet $72^{0}/_{16}$). But with the construction of the embankments after

1963, the problem of meandering towards the eastern bank of Ganga increased drastically. It has also been recorded severelly that as much embankments have constructed natural attack by the river always have destructed them. It is found that striking of river water against the concrete walls of embankments energize the potential erosivity of the water current much compared to the earlier days. After the construction of 5th retired embankment from 1991 to 1998 further erosion engulfed more than 2 km width of bankline for a distance of 10.00 km from Domhat to Panchanandapur upto 1998 and it increased an additional area of more than 11 km.The river Ganga also engulfed the spur no. 24 totally from the tagging point. In the year 1999,6th retired embankment was constructed and the distance between the bank like and the embankment was 350 to 650 m. It was also decided to construct a new spur in the place of spur no. 24. But during construction, it was attacked by erosion and out flanked.River bank line has also come very near to 6th retiered embankment,15m and 32 m at Khaskol and Daulatola point during the end of 2002. Renovation of spur no. 20 and 19 was also decided to be taken up.During flood 2000 the 6th retired embankment was also eroded due to toe cut of the bank. All such evidences prove the fact that with the making of bunds excessive siltation in the riverbed occurs and thereby reduction in the cross sectional area of the river which results into water head pressure specially in the wet season. Thus such a situation creates flood and thereby breaches on the embankments. Discontinous embanking also aggravates the formation of incipient gullies and backward plus headward undermining which cause destruction of the embankments.

Embankments adopted to control erosion and flooding are of 3 categories :

(a) Construction of short spurs to divert flow and withdraw the attacking action to the bank line.

(b) Constructing the bed bars, falling apron and revetment to safeguard the bank from steady slumping.

(c) Construction of embankments to avert flood and erosin, it is of 2 types.

(i) Marginal

(ii) Retired

During 1970-1985 erosion was confined to immediately upstream of Farakka taking about 12 km length of bank.Though short spurs were built but not remained intact. Reconstruction and restoration of these works had to be undertaken year after year until a charland started developing close to the left bank.

From 1985 the river attack was shifted upstream of Panchanandapur. Many short spurs (18-26A) were constructed in this reach to divert the flow from the attacking bank. During flood 1999 undercuting and toe attack outflanked the spurs 26A, 26, 25, 24, 20 and 19.Spur 20 was reconstructed after the 1999 flood which was again outflanked in 2000 flood. Depth of water at the toe of the spurs were 15-20m & with a velocity exceeding 5m sec^{-1} during peak discharge. Thus higher the velocity of water at the toe with subsurface undercut and back cut collapse of the embankment,gradually the entire length of the spur used to be destroyed.One weir mesh contains about 2500 to 3500 boulders and if one part collapses the entire mesh use to be collapsed as they are in a single mesh-work.In many cases the bank connections of the spurs were severed due to back cutting.This resulted an obstruction to flow and diversion through the gap formed between the spur and the bank accelerating the local erosion near the bank connections.With high depth close to almost vertical bank and strong current during failure, attempts to restrict the backward cutting were not possible and successful. Experience oriented statement should be like this,that the making of embankment has energised the river to cut across for many times over the alluvial banks.The hydrology affected by embankment is very severe. On one hand, the river is obstructed and abstained from erosion at the Rajmahat side,whereas the pressure of water head is also obstructed by stone made embankments at the east. For this the water level will rise up to attain more cross sectional area, which will lead to the submergence of the embankment and outflanking of the embankment during rains and deluge associated with toe cut gully formation, back cut and incipient trench formation etc. will lead to resultant collapsation of an entire spur or part of embankment.Ganga Bhawan was completed in 1975 at Panchanandapur. Kaliachak II block. On the 5th September 2003 the famous Ganga Bhawan was totally engulfed. There were 8th retired embankment and Bull headed Dimper and the 700 m tagging bundh as well 500 m marginal bundh.In spite of that back wasting and toe level erosion caused the damage of 25 crore Rs. to initiate such erosion. On 9th September 2003 at 9.00 am morning about 1,000 families of Asrafmunnatola, Hazaritola,Nasrattola, Gangabhabanpara, Palpara and Banutola of Panchanandapur lost their houses (Roy. P, 2004). Scientists and experts opined that excessive embankment making resulted into the acceleration of Ganga erosion to engulf Ganga Bhawan. When marginal embankment has threatened the same action on sets over the retired embankment. The 9^{th} retired embankment was collapsed at panchanandapur almost this way during the Pagla-Ganga river piracy stage. Thus to arrest the natural play of the river by artificial means is normally impossible and any time if this happens to be implemented in reality nature will also play as accordingly as required and that will certainly be detremental to bank protection.

3.2.2.3 Role of the Farakka Barrage

During the opening half of 16^{th} Century when the European traders used to come to West Bengal, Chattogram was known as a big harbour and Saptagram was a small harbour in W.B.Saptagram was situated alongside Saraswati river which was one of the distributory of River Hugli.Afterwards the river Saraswati decayed and the then merchants couldn't reach to Saptagram due to poor navigability of the river Hugli. In 1651, in the month of January East India Company set a new harbour at Hugli (near the jail of Hugli presently).In 1690 they again shifted the harbour to Kolkata and the outcome of Calcutta as a harbour city was found in the 18^{th} century. Before the outcome of Calcutta, the river Bhagirathi was decaying due to shortage of water. After the decaying of Jalangi and Churni the problem enhanced a lot. Before the construction of Farakka Barrage during dry season the discharge at Jangipur through Bhagirathi was only 1.73 cumec (Rudra, 2002).The contribution of Jalangi and Churni was only 100 and 350 cusecs.The so called discharge was not a steady runoff rather base flow or effluent seepage flow.The six Chotongapur rivers (Banshloi-Mayurakshi-Ajoy-Damodar-Rupnarayan) had only rain feed discharge of which 80% used to come in the wet months of July to September and the next 9 months receive only 20% of flow.

For the disability and unability of the contributing rivers the estuary of Hugli was steadily going to be silted up due to deposition of 41 crore ton silts yr^{-1}.Though the problem hadn't been solved after the construction of Farakka Barrage.Due to the Indo -Bangladesh water pact during dry season, 40,000 cusec water still not available at Calcutta port. During high tides the opposite flow (Northward) of water from sea to Hugli river also accelerated the rate of sand deposition. Earlier, the silts could drain out from the river during rains.But after the construction of D.V.C (Damodar Valley Corporation) Masonjore, Kangshabati and Hinglo dams such probability is some how decreased.

To solve the problem administrative action plans were implemented from 1820 to 1871 and there are long run history for this issue.After independence during 1961, 8m drafter sails could not enter to Calcutta port. In 1957 the internationally famous river scientist Dr. Hensen proposed his plan of Farakka Barrage and 38 km long feeder canal to regulate water to the Bhagirathi river and 1,13,267 cumec (40,000 cusec) water to Calcutta port. Not only this, the connecting pivot of Ganga-Bhagirathi at Jongipur was also regulated and somehow disrupted by making Jungipur Dam. It was proved practically wrong in ecological point of view.It is contextually remarkable that at present the water table at Jungipur is 12.80 m and in the dry season near Mittipur the water table was 12.03m only in Ganga i.e. the difference of water level between Ganga and Bhagirathi in dry season is only 0.77m (Rudra, 2000). For this reason during dry season discharge of Ganga grows to have water from Bhagirathi taking through the Jungipur barrage. In 1963, the work of Farakka Barrage started and finished in 1971 and the Feeder canal was established on 21st May 1975.

In every river system discharge (Q), slope(s), length (l), width (y), cross section area (A) and wetted perimeter (P) as well amount of burden to be drained, always maintain a dynamic equilibrium or a balanced state of river hydrology cum river hydraulics within their relationships. The Farakka Barrage had seriously disrupted the dynamic equilibrium. But that was not thought before. It was stated that 'The best and only technical solution of the problem is the construction of a barrage accross the Ganga at Farakka with which the upland discharge into the Bhagirathi–Hugli can be regulated as planned, and with which the long term deterioration in the Bhagirathi-Hugli can be stopped and possibly convert into a gradual improvement.With a controlled upland discharge a prolongation of the freshet period will be obtained, and the sudden freshet peaks which will cause heavy sand movement and bank erosion will be flattened (India: Ministry of Irrigation and Power, Preservation of the port of Calcutta, New Delhi).Anyway the assumption could not fit to the present ecological situation.But the disrupted equilibrium resulted rigorous migration of channel from Rajmahat to Jungipur (74 km length of river). During the building of Farakka Barrage the construction of coufer Dam partially obstructed the main flow of Ganga.After completion of Farakka Barrage the following two reactions coined to the academicians and planners.

(a) Huge siltation in the channel

(b) The straight course became migratory to hold the huge upstream flow/discharge of Farakka Barrage.

To readjust herself in the changed ecology the river started to lengthen its course to hold the huge water coming to it and on the other hand the river also started to increase its width to hold the water as because oversiltatin at the U/S of Farakka resulted enormous bed filling and that resulted to attainment of more cross section area.Such need actually lead to the lateral migration of the river.It is actually natural in any river regime that if there is reduction in bed area bank side area by lateration shall certainly be enlarged.Since ability to transfer a load depends onlow and high water differences,volume of flow, velocity and turbulence in the system(Butzer, 1976).Farakka Barrage has also reduced the turbulence level of the river bed by steady and long periods of siltation. Reduced downstream turbulence favours deposition of heavier materials that were eroded upstream of the interfluves (Butzer, 1976). The obstructed river has no ability to wear down the hard rocks of Rajmahal. Consequently erosion is taking place at the eastern bank of the river. It is now under serious doubt that in future the river will create the channel of its own choice denying Farraka Barrage. The impact of Farakka Barrage has been found both in the upper and lower course of the river Ganga. Some of the major impacts are summarised below:

Upstream

(i) Interception of the flow channel/changed from straight to oblique.
(ii) Sedimentation (640×10^6) metric tones year^{-1}.(As per Banerjee,M)
(iii) Reduction of the cross sectional area
(iv) Declining slope of the long profile
(v) Widening of the river and increasing length
(vi) Increase in flood frequency and magnitude
(vii) Severe bank erosion and displacement.
(viii) Rising ground water table
(ix) Tendency to bypass the Farakka Barrage also Kalindre – Mahananda.

Downstream

(i) Land reallocation from right to left
(ii) Population displacement

(iii) Indo-Bengladesh border dispute

(iv) Falling ground water table

(v) Communication delinkage problem

(vi) Threat to Farakka Barrage at Farilpur point

It will take a more straight and easiest way of canalization either by taking Kalindri, Chota Bhagirathi or Pagla separately or jointly the all. The planners of the project could not think about tremendous future situation. They only thought about the then present problem of Kolkata port. Wining the nature should then only be possible if you abide bythe river and development should also be abiding by its desire (Rudra, 2000). This will seriously affect discharge condition. Upstream and dowstream of Farakka Barrage there is always quite differences in value of discharge. Discharge fluctuates between low and high water with great differences of level,volume and velocity (Butzer, 1976).

The Ganga can't go to Mahananda along such a tortous route, But perhaps this generalization is not fitting to the reality. The river has its own history and its own role over alluvium.For example, Bhagirathi has changed its source with the migration phases of Ganga for about 35 km south-east. Rennell's report in 1787, the report of Steevenson Committee and Major Hirst's reports, the history of Bengal' by Adams William etc. prove the shifting history of river Ganga. The gauge level of the river Ganga both at upstream and downstream of Farakka Barrage has been shown in table 3.11 and figure .

Table 3.11 Daily gauge level both up and down steam at Farakka of the river Ganga

Date	Upstream water level (m)	Downstream water level (m)
29.8.1975	24.12	23.75
23.9.1976	24.62	24.05
18.8.1977	23.73	23.3
21.8.1978	25.66	24.52
31.7.1979	22.67	22.6
7.9.1980	24.88	24.64
6.8.1981	23.83	23.41
9.9.1982	24.76	24.29
22.9.1983	24.93	24.41
15.9.1984	24.75	24.15
20.10.1985	24.45	24.03
6.8.1986	24.54	23.97
13.9.1987	24.54	23.96

01.9.1988	25.44	24.62
09.9.1989	22.82	22.58
09.8.1990	24.14	23.78
12.9.1991	25.29	24.86
21.9.1992	23.91	23.67
28.9.1993	24.1	23.83
18.8.1994	24.95	24.62
14.9.1995	24.01	23.84
03.9.1996	25.06	24.77
08.9.1997	24.13	23.86

Source: FBA, 2000

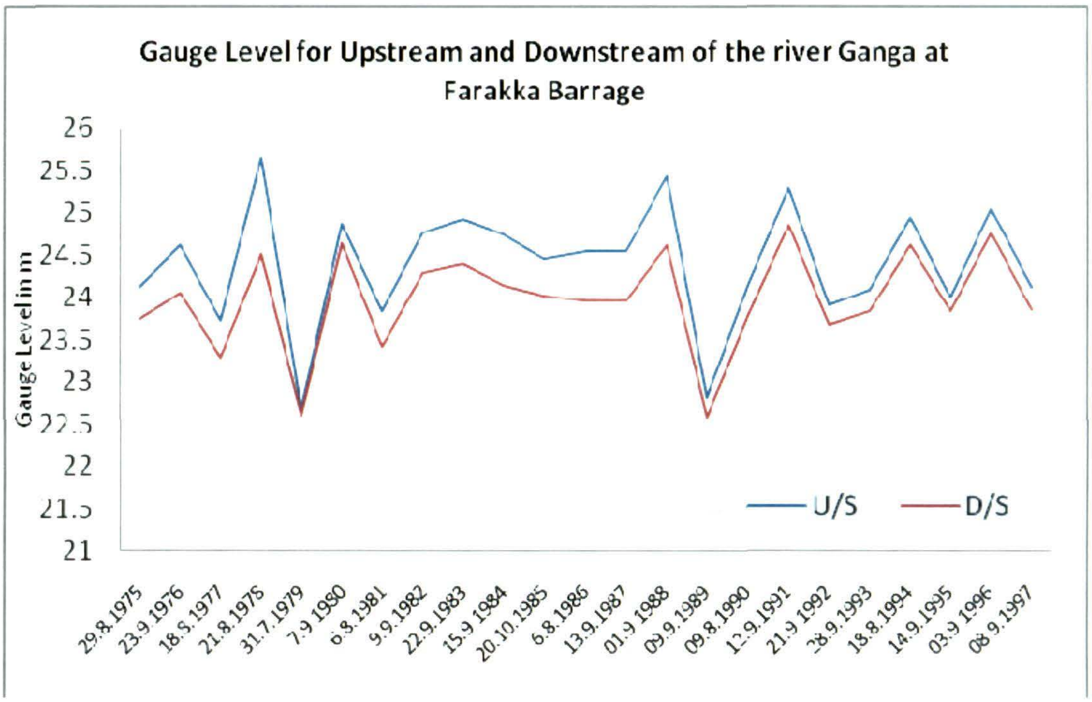


Figure 3.8 Gauge Level of the river Ganga both Upstream and Downstream at Farakka Barrage

Thus the difference of water table head at the upstream and downstream part of the barrage is continuously existing and the upstream table is higher (averagely 24.36 m from 1975 to 1997) compared to the downstream table (averagely 24.04 m from 1975 to 1997). Thus existance of hydrostatic pressure on the barrage and back water pressure in the main channel boundary (Malda side) of the River Ganga is a result of unsteady discharge over time of the river at the Barrage point. Starting from 1975 to 1990 the difference was more or less unchanging but after 1994 to the flood of 1997*(Fig.3.8,a,b &c)* and onwards the difference increased very much. The following table is showing the variation of width of the channel at places. Variations show reduction of width to only 2.65 km at Barrage from 4.2 km to 4.8 km at Khaskol & Sakullapur. The consequence is that the reduction of width and cross section area of the river is incapaciting the load holding efficiency of the river. At Panchanandapur the width is about 4.35 km which is only 2.65 km at Farakka i.e. a reduction of 1.7 km *(table. 3.12)*. For which reaction s of back water pressure at the Farakka pond section and over the channel boundary in the upstream section is increasing in due course of time resulting into huge bank erosion occurences. Thus the barrage is indirectly affecting the natural hydrodynamic adjustment of the River.

Table 3.12 Spot-wise width of main channel (LC) of River Ganga.

Sl. No.	Location	Width (km)
1	Manikchak ghat	2.00
2	Domhat	2.30
3	Moyanapur	2.30
4	Aswinitola	2.55
5	Khaskol	4.20
6	Sakullapur	4.30
7	Panchanandapur	4.35
8	Ramnagar	4.30
9	2 km u/s Farakka	1.75
10	1 km u/s Farakka	1.76

Source: IRS LISS-III Imagery, November, 16, 2007.

3.3 Fluvio-Geomorphologic Characteristics of the River Ganga

The study on sequential changes in the course of Ganga, Ganga-Padma river system within West Bengal through applied Geomorphological studies during pre and post Farakka Barrage construnction based on comparative analysis of the SOI toposheets / PS (Thana) maps of Bengal survey and time series IRS imageries(1996,1997,1999,2003,2007 etc.) show a serpentine nature of channel shifting of the River.The river enters West Bengla from North West of Rajmahal (in Bihar) flowing in south-eastern direction, further downstream splits into two branches. The main channel flowing through Malda and Murshidabad is commonly Known as Padma reaching Bangladesh. The southern flow (branch) is known as Bhagirathi Hoogly. The changing nature of Ganga is a prehistoric one. The latest major change possibly occurred in the last decade of the 18th century which may have some interrelationship with the changing courses of the Tista-Brahmaputra system due to some neo-tectonic activities. Abandoned channels, left out meander scrolls, ox-bow-lakes, remnants of spill channels, older flood plains and lineaments etc. provide a synoptic coverage of the play field of the Ganga (NIH, Patna, 2003).The Pagla river,an offshoot of Kalindri river, from south of Bhutni char was flowing in a curvilinear fashion upto Gopalpur and then flows in two branches with highly meandering course. The upper portion of Pagla is cut off from Kalindri. Pagla splits into two branches, south of Gopalpur and now (after capture) receive water from Ganga.The eastern branch is flowing eastward and then southward passing across the ruins of 'Gaur'.The other Branch flows southwesterly (NNE of Farakka Barrage).Further, Pagla passing through Kaliachak of Malda with a tortous channel, join the Gaur-side branch of Bhagirathi and goes to Bangladesh. The Pagla is the present day imprints of former Ganga course between 800 A.D. to 1,600 A.D.The specific change of Ganga during 1,700 A.D. had some interlinkages with the change in course of the Tista River in 1787 and the Brahmaputra river in later part of 18th Century probably due to some geo-tectonic reasons.Manikchak–Gopalpur sector (active zone of erosion) experienced 700 m shifting of bank in 1997. From SOI sheet 72P/13 (1971) and imagery 1997, 2003 etc. proved the engulfing of Pagla and straightening of the large extent of the river.The prediction held true by the occurrence of 1998 flood. But during 1989-1999, below Farakka Barrage observation of insignificant change in course was observed. Earlier map of survey of India showing the river reach between Rajmahal and Farakka indicate wide lateral shift over periods.Survey maps of 1922-1923 and 1936-1937 show the straight channel of the course of Ganga (I&W, Govt.of West Bengal,2004).Crescent shaped abandoned lineaments of paleo channels with that of settlement lines near left bank of ancient time evident the fact truthfully. The line demarcating the normal habitation and sparse habitation has been termed as differential settlement line. A number of small pools all along and adjacent to the differential settlement time has been found. The line joining the adjacent pools has been marked as *Margang* (dead channel) on the 1922-23 survey maps. The vertical heights of the channel charlands near the water edge has been measured to be 2 to 3.5m whereas the normal heights of the older bank ranged between 5.5 to 6.00m.The findings lead to acknowledge that the differential settlement lines were the left bank line of Ganga in the ancient time probably when skirted from older Bhagirathi and latar on leaving Kalindri and took a most westerly line-duirng the phase it left Manikchak, Inayatpur, Dharampur, Chandipur Nathinagar, Bhawanipur, Mohonpur, Khaskol and Gosainpur.The culminatory shift focusses the beginning of the last century hugging almost the right bank like 1922-23 as reported by I&W Department, Govt. of West Bengal in 2004. But the river could not stay as stationary and started its journey to the left again leaving the straight alignment between Rajmahal to Farakka as viewed in 1971 SOI sheet (72O/16). Image 1994, 1997, 2003 and 2007 evident the sequence of eastward migration. During this phase the exteme look has been put forward to the crescent of Manikchak-Khaskol-Sakullapur-Panchanandapur.Between Farakka and Khaskol the previous bank line was aligned to the right of Gosainpur and Hussainabad. For such incidences the main possible reason was progressive diversion of flow from the master channel through the secondary off shoots over and alongside the progressive charlands i.e.channel bars.At Rajmahal the river follow a narrow neck or funnel like shape of channel of about 2.35km wide with an average depth of 10m below the pond level (21.96m GTS) (I&W, 2004 pp.6). The thalweg skirting the right bank of Rajmahal touches and hugs the left bank at Manikchak.Below Rajmahal the river for a distance of only 10km enlarges its width for about 12km. The main channel takes off 2 important off shoots below Rajmahal. One is the central and the other is the right channel.The channels flow through the convex sand bars. The right one takes off 2 km downstream of Rajmahal and traverses for 16.55 km and finally debouches into main Ganga channel at the more southward location. The average depth of the channel is about 4m below the pond level. The Central one takes off for 7.00 km and joins the central almost few above parallel to the junction of right and main channel. Its depth is about 5m below pond level. The chars located either side of the channels have almost flat to few inches elevation and tending to be submersible during floods and storm rains. At few locations downstream, the width of the right and the central offshoot is only 0.55km and 0.34 um respectively (550m and 350m). During 1980 such right channel was non-exiting. After 1980s to the onset of 1990s the right and the central one carried water share from the main channel but not developed to such extent that it could be signified as a pilot channel of the main one. From then the main channel having been independent from the other two, started to shift leftward laterally and the areal extent of the convex sand bars on the right extended. The morphology of the right channel started on 1990s and completed by 1997 and development continued till date.On crossing from right bank to the left, the thalweg hugs the left bank adjacent to Manikchak ghat to a certain distance. The next 1.5 km, it follows the left bank and an additional length of 7 km i.e. for 8.5 km. The next hugging is at Khaskol-Panchannandapur bend which is termed as the apex of the meander bend. The depths above local datum of 2 or 3 m stands for about 20m to 22m below datum level. Here the bank alignment is almost vertical and shape is meander- head concave owing to regular cum tremendous slump over the soft alluvium. Not only this, but the average width of the bank is about 1,500 to 2,000m here at pond level .Keeping this hugging bend the thalweg now reaches to the right bank near Ramnagar just 1.0 km upstream of Farakka Barrage and in Murshidabad it hugs the right bank reaching to the next bend of inverted meandering 'S' structure .The crow fly (straight) distance between Rajmahal and Farakka is only 29km whereas the thalweg distance is 43.5 km.The sinuosity index is 0.66km which indicates the magnitude of meandering of the course.

Investigation was carried out on the perception of the affected people regarding the causes of river bank erosion by the Ganga river through questionnaire survey (106 respondents). The salient findings have been tabulated in table 3.13.

Table 3.13 Causative factors of bank erosion: A stakeholder's perception.

Perceptions	**% of Perception defender**
(i) 'Will of Allah' (God's desire)	07
(ii) Floods of yearly recurrence	20
(iii) Impinge flow / current attack	05
(iv) Unprecidented rain (Wet season)	08
(v) Excessive embankmenting	25
(vi) In-channel bar/Char formation	10
(vii)Loose lithology of the Bank soil	25
Total % of Perception defenders	100

Source: Interpersonal and Group interviews, 2007 (June) and 2008 (October).

Conclusion

Thus the evidences of bank erosion in Malda district has found very much governed by the causative factors of both physical and socio-cultural types and even the architectural attempts have found partially responsible behind the occurrences of age old bank erosion.Actually relief aspect with that of very low to negligible general slope of the district have affected the detained discharge of the River through its main channel. Similarly the other two off shoots like the central and the right channel is not enough capable to share the burden of the main channel.Regular wash out of the channels is also disrupted due to over siltation of the channels and has accentuated the chances of flood frequency.Climatic parameter like rainfall and heavy showers have also increased the possibilities of saturation of the banks. Strong ebbs and impinge flow attacks provoked by the secondary currents and helical flows have also aggravated erosion.The locational hadicappedness of the district in terms of hard shield rocks of Rajmahal belt and the softer alluvium of the Diaras have consequent imbalance of river current attacks.One of the banks(Rajmahal side) of the river is quide hard ,while the athor being so soft is susceptible to experience the water head pressure reactions.The river in this section is also fatigued in terms of its high potential energy and low kinetic/dynamic energy factor.Starting from Manikchak to downstream of Panchanandapur the shear stress has exceeded the channel boundary resistence and factor of safety is many a times less than 01 or even less than 30%.Human interferences in the form of charland settlements,architectural activitieslike spur making,barrage buildings etc. have accentuated the degree of erosion.But physical factors have been emphasized as more prominent and are seriously dominating compared to the socio-cultural factors. In relation to the active and steady phases of erosion river hydraulics has been found one of the most accelerating factors.

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