IN-CHANNEL MECHANISMS AND RELATED RIVER ENERGY: A CASE OF GANGA RIVER IN MALDA DISTRICT, WEST BENGAL, INDIA

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Abstract
The activity of the major river like Ganga is influenced mainly by its fluid dynamics, sediment load, and energy differentials from one segment to the other segments, which having been facilitated by the country rock and its slope, soil character, weathering pattern in particular. The interplay of these conditional facilitators over the time frame actually results into river erosion. The energy of the river is a cumulative outcome of mass of the fluid, river load, acceleration due to gravity and slope inclination over the basin. The increment in magnitude of these, actually transforms the energy in potential to more dynamic or Kinetic in character. The river itself is always in action to maintain the dynamic equilibrium to accommodate its load and to keep a balance between the input and output of load within the channel from the upstream to the downstream direction. There action of which in true sense consequent upon river widening, initiation, and head ward corrosion.

Keywords: Slumping, embankment, discharge, potential energy, kinetic energy, initiation, head ward corrosion, velocity, shifting.

Introduction
The mighty and sacred river of Hindu mythology is the river Ganga which nourishes millions on its bank as it devastates during unprecedented swinging within its flood plain taking a wide area of its catchment basin. Ganga on the downstream of Maharajpur in Bihar flows on the right side of Bhutnidiara and then enters into the district Malda. The maximum depth or thalweg line of the main channel more or less hugs the left side bank taking the country rocks between Manikchakghat to Panchanandapurand and thereafter takes a sharp turn towards the right bank below Farakka Barrage entering into Murshidabad District.

The problem of erosion along the left Bank of river Ganga at upstream of Farakka Barrage in the district of Malda has been of serious concern since early sixties, but the problem exaggerated to a greater degree and ultimately reached to a forcible situation during post Farakka days. Since 1931, the reach between Rajmahal and Farakka was almost straight as per a crow fly path but the river started meandering and scouring bank side villages and in 1963, the village Panchanandapur, about 20 km upstream of Farakka Barrage, was found severely eroding. A total land of 14,335 hectare has been eroded in the district of Malda during the period from 1931 to 1978.

From 1988 onwards, devastating slumping was noticed on and downstream of Manikchak up to Moynapur (Aswinitola) and during the period from 1988-1991 tremendous erosion engulfed more than 2 to 3 kms width of bank line for a distance of about 10 km from Domhat to Panchanandapur. The river Ganga also engulfed the spur no. 24 totally from the tagging point in that very period. The Bhutnidiara circuit embankment near Nanditola was seriously damaged due to bank side slumping in this year. During flood of 2000, the 6th Rtd. Embankment was washed away due to erosion. During receding flood the river was gradually attacking the spur no. 20 and subsequently the nose of the spur was settled along with the total engulfment of spur no. 19. During flood 2000, about 560 m length of bank near village Janutola was wiped away.

In the year 2001, decision of the construction of 8th Rtd., embankment was taken up to protect the vulnerable bank line which was very close to the toe level of the 7th Rtd. embankment having a minimum distance of 264 m at Jagirtola. The marginal embankment was remodeled as a deflecting spur by left out the spur no. 20 which was acting as a serious spur against impinging flow of water. In the flood 2001, 7th Rtd. bank was eroded away having a length of 1200 m near Jagirtola and Jahidtola. After the engulfment of spur no. 20 and 18 Gangabhaban which was the famous guest house of Irrigation and Waterways departments at Panchanandapur was under severe threat. The 4th Rtd. embankment near Manikchak and Harischandrapur was under threat and engulfed in the river very soon. Several such fact files can be pointed out to evident the severity of such menace.

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Study area
River Ganga within Malda District has been chosen as the study area. The District comprises about 3566.17 sq km area and its extension based location is 24°40'20"N to 25°32'08"N and from 87°45'50"E to 88°30'0"E respectively (Lambourn, E.G 1918). The District Malda is situated keeping Jharkhand in the west, Bangladesh in the east, and Murshidabad district in the south whereas, the river Ganga delineates its western boundary and the northern part of the district is bounded by the North Dinajpur District. From the physical point of view the District is divided into three identified parts namely TAL (in North and North-West), DIARA (in the south west) and BARIND (in the East). Barind is characterized by undulations with successive mounds and depressions, Diaras are the alluvial lands created mainly by the joint actions of erosion and deposition by the rivers Mahananda and Ganga in the Pleistocene- Holocene (recent) age. The ‘Tal’ tract is dotted with many small depressions or lakes which are practically a low lying area. The general slope of the entire district is not more than 2 to 3 degrees; whereas ‘Diara’ is characterized by very lower the slope of less than 2 degrees. The slopes are directed generally from the north to the south (Sengupta, 1969). Up to 2001, the amount of land loss in the grasp of the river was 902 hectare. The high propensity of erosion was continued up to 2007-2008, and afterwards of 2008 pocket areas mainly nearer to Fulahar Ganga and parts of bank near Manikchak was highly attacked.

Materials and Methods
a) Study of different literatures and related review have been carried out, mainly books, research papers, maps etc.
b) Fluid data like discharge (Q) was collected from secondary sources especially stage analysis results from the secondary sources for river energy model study. Data of mean fluid density (DMD) has been done by averaging the data of specific locations found in secondary sources and laboratory tested results. Magnitude of gravity has been calculated latitude-wise from satellite image platform of November, 2003 with the help of the following formulas:

\[ g' = g \left(1 - \frac{h}{R} \right) \]

Where, \( h \) = Height of the spot from sea level.
\( R = \) Radius of earth (M.K.S. system; \( R = 6400,000 \)M)
\( g = 9.8 \) m/s\(^2\) (standard)
ii) Site specific calculation

\[ g' = \frac{g}{(1 - \frac{1}{288} \cos^2 \alpha)} \]  
(Daskhan, M 2007)

Where, \( \alpha \) = latitude  
(Duari M. & Mazumder A.2004)

Height data was collected from GSI maps of 1:15,000 scale by close examination and contour study with spot height investigation having a view to choose the nearest value of height of the point of study i.e. either by taking the nearest contour value or by spot elevation.

Potential energy was calculated with the following formula.

iii) \( WZ = EP = m.g.h \)  

Where \( EP \) = potential energy.
\( W \) = Weight of the fluid equivalent to mg
\( Z \) = location- wise elevation difference
\( g \) =constant of gravity=height difference between two corresponding points under analysis
\( m \) =mass of the fluid which is a multiplier effect of discharge of water (Q) and density of the fluid (D)

Whereas kinetic energy was computed with the formula given below

iv) \( EK = \frac{mv^2}{2} \) where, \( EK \) = kinetic Energy  
(Moriswa, 1968)

\( m \) = mass of water and \( v \) = fluid velocity

The entire study aims to analyze a gross idea about river energy against loose bank- shearing stress and heavy fluid energy.

**Major causes of bank erosion**

**Natural causes**

**Geology of Bengal Basin and course change of Bhagirathi-Hugli**

The area of Ganga-Brahmaputra basin is about 1, 50,000 sq.km. In a depressed synclinal shield region the accumulation of crewwhile as well as present day river load during a prolonged period of about 70 lakh years, such a basin plain was formed. Geologist named this basin as Bengal Basin. The general deposition rate of Ganga - Brahmaputra river basin was amounted to be about 166.70 crore tons per year in a fashion of multicyclic layering and ultimately such a synclinal basin configuration was attained. Within this extremely silt laden basin region, each sq. km area amounted to receive about 10.30 lakh cubic m water through rainfall in a year. Taking the Ganga -Brahmaputra system, such a exorbitant quantity of discharge of almost entire north east India passages out and reach to the Bay of Bengal. Keeping Meghalaya plateau at the eastern and Chotonagpur shield at the western part of the narrow passage of this basin consisting of an average length of 20 km the Bengal gap (Rajmahal-Meghalaya gap) area allows the ice molten water of the rivers of Uttar Pradesh, Nepal and Tibet to be debouched which is a far-fetched hydraulic pressure inside the channel area. Through this gap, actually the discharge of water (roughly 85,000 crore cubic m) of the Brahmaputra, Teesta, Mahananda and other rivers of North Bengal takes their passage to further south east. But the competency of the river Ganga to contain such an excessive discharge of water within its cross section area leads to spate outward as flash flood. Ergo the frequency of recurrent deluge periods is very common in Malda, Murshidabad and both the Dinajpur of West Bengal.

During the last two centuries, responsibly for the subterranean tectonic forces from within the earth, the geologic beds of the basin are slanting eastward i.e. from the Middle Eastern India towards the Bay of Bengal direction. To respond the changing topography in relation to geologic structure, many of the rivers have grafted a new tendency to shift eastward keeping their previous channels as paleo offshoots or abandoned channels especially after the periods of withdrawal of deluge. In the earlier part of 17th century, Teesta was flowing through the three rivers of North Bengal like “Karotoya”, “Atreyee” and “Punarhhaba”. But after the severe flood of 1987 Teesta took its present course east ward in direction to join Brahmaputra. In 1916, Major F.C. Hirst analyzed that the entire region from northern part of Jalpaiguri to southern Barisal of Bangladesh is simultaneously depressing towards Bay of Bengal. In 1959, two great Geomorphologist, Morgan and Makintire published an article and analyzed that in Bangladesh the bed of Brahmaputra i.e. Yamuna is gradually depressing due to excessive pressure of silts and debris within the cross section area of the river and is affecting the rivers akin to the same system specially the Ganga to take an eastward tendency of shifting which in turn has become a mishap to the mighty Ganga. Reasonably for which, the east bank side of the east Indian rivers is more or less standing with high bank elevations or eroding banks and consequently, the distributaries like Bhagirathi, Bhairabi, Jalangi etc. are being delinked at their source points from Ganga.

**Ganga-Bhagirathi: the history of Bifurcation**

Near Mithipur, 40 km south east from Farakka Barrage in Murshidabad, Ganga is bifurcated into twin flows, one is **Bhagirathi** and the other is **Padma**. After passing 60 km path, Padma has entered into Bangladesh and the other one is mostly a spill channel flow i.e. Bhagirathi has been flowing for 500 km southwards and has reached to Bay
of Bengal. From Krishnanagar to Gangasagar, this part is known as Hugli. In the dry season, the water level of Ganga happens to be 1 m below than the base level of Bhagirathi and incidences of inverse direction of flow known as effluent seepage or efficient flow from channel subsurface layers of river Bhagirathi to Ganga occurs.

The source point of Bhagirathi has been shifted to 35 km south east from the previous with the changing course of Ganga. The first description of the history of Ganga-Bhagirathi bifurcation has been found in the letter of Tavernier written to Barnier on 6th in 1666 January. In 1788, in the geographical account of “Rennel” named “Memoir of a map of Hindustan”, the history of bifurcation has been focused much. Then, Bhagirathi was bifurcating from Ganga near “Suti’ of Murshidabad. The Cossimbazar branch was almost dry from October to May and Jallinghy is in some year not navigable during 2 or 3 driest months. Major Colbrooke wrote in an article published from Asiatic Society in 1801 that the Ganga-Bhagirathi connection was found at two sites one is Mohongang near Farakka and the other is Suti.

But after Mohongang, there were imprints of severe sites of bank erosion locally known as pahal in Murshidabad and Bhangan in Malda. Colbrooke wrote-“The quantity of land which has been here destroyed by the river, in course of few years, will amount upon most moderate calculation, to 40 sq. miles or 25,600 acres’. Vivid descriptions of Bhagirathi bifurcation can be obtained from the annals of Irrigation and Waterways Department from 1824-1852. In 1824, the originating point of Bhagirathi was near Suti, 22 km away from Farakka Barrage. But in 1825 Ganga shifted for 11km south west away from Farakka Barrage and captured some of the parts of the Bhagirathi. Near “Chokka” which is 12 km south east from Farakka a new source point was attained in 1828. From 1825-1830, the connecting point was again shifted for 5 kms more south east ward. It was 5 km north from Suti. In the following two decades from 1820-1840, Ganga and Bhagirathi changed their course for several times from Suti to Chokka. In 1847, to survive the flow of Bhagirathi in dry seasons a 3 km long passage way was formed from Suti to eastward Bhagirathi. In 1871 during the flood period, a new source point of Bhagirathi was found near “Chourashia” away from Suti, which is 10 km south east from Suti. In 1882, near Joyrampur another source was cut from Ganga to regulate water to Bhagirathi. So, Jallangi was treating from then as the main way of trade and transport. Captain Broom pointed out Jallangi was used as main line stream from Calcutta to Goalundo during rains from 1858 to 1886. But, subsequently it deteriorated and Mathabhanga was used for navigation in 1882. The situation existed quite up to 1884 and afterwards it gradually deteriorated. By 1890, it became so deteriorated that the river was abandoned in favour of navigability and it was never used since.

In 1925, survey of India toposheets observations were put forward to witness that Bhagirathi was adjoined with Ganga at 3 consecutive points; the first one was near Nayansukh, second one was near Suti and the third one was near Giria. Then, from Nayansukh to Giria, Ganga was flowing almost parallel with Bhagirathi and char of 77 sq. km was deposited within Bhagirathi and Ganga. But in the following decades, the right bank of Ganga was gradually eroding and was shifting west ward. In 1974, in the maps published by survey of India, from Nayansukh to Giria a course length of 35 km of Bhagirathi was captured by Ganga. Sankopara, Nayansukh, Nimtata and Suti villages were totally destroyed in the grasp of the river Ganga. Only at Giria, Bhagirathi Ganga connection was maintained. In 1975-1980 Giria was left behind and the source point of Bhagirathi came to Mithipur. A man made barrage was also architectured to delink the natural connection of Bhagirathi with Ganga at 2 km west from Mithipur. It was to stop the reverse flow from Bhagirathi to Ganga in dry seasons. Technological man and his artificial approaches within the basin always played an intention of obstruction towards the river dynamics.

Mechanisms of in channel Hydraulics of Ganga in Bengal alluvium

Stream does more than shift and transmit sediment load by repeated scour and fills (Butzer, 1976) along the bed and with high magnitude where challenges from architectural river regime. They actively erode by

- i. Channel deepening or by down cutting of the stream bed i.e. initiation
- ii. Channel widening through bank curving or undercutting i.e. bank slumping
- iii. Channel extension that is head ward or Regressive erosion by Streams and Gullies i.e. head ward corrosion

This erosion is of two basic types in the case of river Ganga. Firstly, the valley floor over plains of Bengal consists of river laden sediments of alluvium where the river readjusts herself in little erosion and deposition. As a new channel is formed, an older channel is abandoned and filled, or as one bank of the meandering mighty Ganga 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 having a mechanism, whereby the river makes short or long term adjustments. Secondly streams cut their way into upland where they usually erode into comparatively harder or compact rocks.

But the mechanism and rates of erosion in bed rock are different and the ultimate effect is to sculpture the interfluves. This factor is less effective in the case of Ganga.

Cutting the established channel of Ganga involves bed erosion, bank undermining, and bank collapse. Erosion of the alluvium on the river bed involves lifting and pushing of loose particles, particularly by turbulent waters. Any cementing matrix in older alluvium under the bed or in the river partly dissolved and individual are loosened by mechanical wear.

Bank collapse occurs also as the river banks of the mighty Ganga are under cut. At some critical angle, the bank slope becomes unstable, and the upper part of the bank falls in or slides down, producing a gentler slope until undermining begins anew.

In case of river Ganga, bank collapse is also aided by ground water seepage or effluent seepage towards the river in the dry months of the year i.e. from March to August.

Pipelines of natural origin which carrying the subsurface water flow of ground water through seepage make the bank side walls more fissured and thereby along the fissured break points bank slumping is aided by striking impinge flow currents of the river.

From structural point of view, the river bank materials mainly consist of cohesive silts and clays and where a high proportion of the river load is carried out in suspension, channels advancing more concave and steep banks and deep cutting channels. However, silt made bank lose their cohesiveness as they become saturated at time of high water; as long as the water level remains high, hydrostatic pressure may support the bank; however, when the water drops, the bank may cave in. On the other hand, loose sands or gravels tend to fall into channel, maintaining steep banks that are quite unstable. Ergo egregious susceptibility to erosion takes acceleration and greater quantities of bed load residuals are immediately available about 100-150 m away from bank as well as the bank foot. This favours channel widening instead of channel deepening reducing down the cross sectional areas. For which actually, leading conditions of secondary and shallow channels start to develop. Such channels may be short-lived till the occurrence of further deluge, since bars and gravel shoals develop, deflecting the stream or forcing the channel to subdivide along the in channel bars. The severity of erosion has increased after the construction of Farakka barrage (Rudra, 2002).
New channels are cut into alluvium by gullying. Gullies are extending during period of rain when surface runoff pours into a drainage line undercutting the head and incising the floor. Piping accelerates headward erosion in some areas, while soil fall can widen a gully at any time. Overflow of channels and bifurcation can also be accelerated by gullying, when water spills over a breached part of older and erroneous alluvium. A gully continues to form where the water plunges down and cuts back until a major channel has been eroded. Thus development of gullies cum bad land formations accelerates the problem up to an alarming situation.

In the following discussion the model study of river energy based on few empirically obtained databases has been done to signify the degree of effects of energy increment with the downstream movement of the river.

**Potential Energy**

The power of the river is defined as the power of erosion, transportation and deposition (Rauf, 2006). Whenever, sources of water increase and are debouched in the channel, velocity of the river also increases and thereby the strength of the river increases and normal to critical attitudes are introduced in the river behavior. Thus, river flow is directly related to the river energy (Rauf, 2006). Static energy transfers into dynamic energy. All such theoretical cognition can be judged in case of river Ganga through empirical estimations of power formula.

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).

\[ EP = WZ = m.g.h \]

Where, 
- EP = Potential energy
- W = weight of fluid equivalent to m.g.
- Z = elevation difference (m)
- h = equivalent to value from Z
- g = graving (9.8 m S^-2 Normal)

In the present study four stretches of locations had been considered from upstream to downstream of the river.

<table>
<thead>
<tr>
<th>Sub-Reach</th>
<th>Identity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location 1</td>
<td>Manikchak to Aswinitola</td>
</tr>
<tr>
<td>Location 2</td>
<td>Aswinitola to Khaskol</td>
</tr>
<tr>
<td>Location 3</td>
<td>Khaskol to Panchanandapur</td>
</tr>
<tr>
<td>Location 4</td>
<td>Panchanandapur to Farakka</td>
</tr>
</tbody>
</table>

In the following paragraph, location-wise computations on river Energy have been done.

**In Location 1**

\[ EPL_1 = m_1.g'1. h 1 \]

Where, 
- \( Q_1 = \)discharge of water = 16969 m^3 sec^-1
- \( m_1 = (Q_1 \times D_1) \)
- \( D_1 = \)Fluid Density = 1.58 gm / cc.
- \( h_1 = \)height difference between two corresponding points under analysis = 25.6 – 24.3 = 1.3m
- \( g_1 = \)gravity = 9.770 m Sec^-2

Thus, \( EPL_1 = 34,05,26,170 \text{ JS}^-1 \) (4.41%)

**In location 2**

\[ EPL_2 = m_2.g'2. h_2 \]

Where, 
- \( Q_2 = 28289 \text{ m}^3 \text{ sec}^-1 \)
- \( m_2 = (Q_2 \times D_2) \)
- \( D_2 = 1.62 \text{ gm cc.} \)
- \( h_2 = 24.3 – 22.5 = 1.8 \text{ m} \)
- \( g'2 = 9.780 \text{ m sec}^-2 \)

\[ EPL_2 = 8.0675928 \times 10^9 \text{ Joule sec}^-1 \]

**EPL_2 = 80, 67, 59,280 JS}^-1 \) (10.45 %)

**In Location 3**

\[ EPL_3 = m_3.g'3. h_3 \]

Where, 
- \( Q_3 = 45262 \text{ m}^3 \text{ sec}^-1 \)
- \( D_3 = 1.75 \text{ gm cc}^-1 \)
- \( m_3 = (Q_3 \times D_3) \)
- \( h_3 = 22.5 – 21.00 = 1.5 \text{ m} \)
- \( g'3 = 9.785 \text{ m sec}^-2 \)

\[ EPL_3 = 1.163170823 \times 10^9 \text{ Joule sec}^-1 \]
= 116, 31, 76,823 J S⁻¹ (15.07 %)

In Location 4

\[ EPL_4 = m_4 g \cdot h_4 \]

\[ Q_4 = 76739 \text{ m}^3 \text{ sec}^{-1} \]

\[ m_4 = (Q_4 \times D_4) \]

\[ D_4 = 1.80 \text{ gm cc}^{-1} \]

\[ h_4 = (21.00 - 17.0) = 4.0 \text{ m} \]

\[ EPL_4 = 5.4080736 \times 10^9 \text{ Joule sec}^{-1} \]

= 540, 71, 78,632 J S⁻¹ (70.07 %)

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 location2, 10.07% is found within the location3 sub reach whereas 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 and Khaskol areas up to Farakka with slope as low as 1:21,000 (valentine, 92) and average velocity of only 1.93 m sec⁻¹. Under this present condition, the bank side water depth adjacent to above said areas is 20 m (+) below the pond level, where as 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 and composed of loose sandy, silty, lithology is highly susceptible to in channel slumping mainly by liquefaction, bank side fluting and block wasting or avalanching part by part.

Table 1: Velocities in m s⁻¹ near the eroding left bank between Khaskol and Panchanandapur

<table>
<thead>
<tr>
<th>Absolute</th>
<th>Discharge</th>
<th>Location 1</th>
<th>Location 2</th>
<th>Location 3</th>
<th>Location 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cusec</td>
<td>m³/sec</td>
<td>Along bank</td>
<td>100 m away</td>
<td>Along bank</td>
<td>100 m away</td>
</tr>
<tr>
<td>6</td>
<td>16969</td>
<td>1.49</td>
<td>1.35</td>
<td>1.12</td>
<td>1.35</td>
</tr>
<tr>
<td>10</td>
<td>28289</td>
<td>1.79</td>
<td>1.62</td>
<td>1.20</td>
<td>1.20</td>
</tr>
<tr>
<td>16</td>
<td>45262</td>
<td>1.93</td>
<td>1.71</td>
<td>1.20</td>
<td>1.20</td>
</tr>
<tr>
<td>27</td>
<td>76739</td>
<td>5.19</td>
<td>4.71</td>
<td>2.53</td>
<td>3.69</td>
</tr>
<tr>
<td>Mean</td>
<td>167259</td>
<td>2.6</td>
<td>2.36</td>
<td>1.51</td>
<td>1.86</td>
</tr>
</tbody>
</table>


Table 2: Extracted velocity assessment (Composite framework of all Locations)

<table>
<thead>
<tr>
<th>Locations</th>
<th>AV. Velocity along the bank</th>
<th>Mean</th>
<th>AV. Velocity 100 m away from the bank</th>
<th>Mean</th>
<th>Grand Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.49</td>
<td>1.12</td>
<td>1.27</td>
<td>0.97</td>
<td>1.21</td>
</tr>
<tr>
<td>2</td>
<td>1.79</td>
<td>1.20</td>
<td>1.35</td>
<td>1.13</td>
<td>1.37</td>
</tr>
<tr>
<td>3</td>
<td>1.93</td>
<td>1.20</td>
<td>0.97</td>
<td>0.63</td>
<td>1.18</td>
</tr>
<tr>
<td>4</td>
<td>5.19</td>
<td>2.53</td>
<td>5.22</td>
<td>1.65</td>
<td>3.65</td>
</tr>
</tbody>
</table>

Source: I & W Deptt. W.B, 2004

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 respond to the down slope movement of the mass of the liquid governed by the factor of mass, amount of gravity imposed and angle of displacement over the bed of the channel i.e. magnitude of slope. To Moriswaa, 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 $E_K = \frac{1}{2} m v^2$ 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 1 to the downstream part of location 4.

$$E_K = \frac{1}{2} m v^2$$, thus applying the formula

$m = (Q x D) =$ mass of the fluid  
$v =$ mean velocity.

Here location wise computation is as thus,

$L_1 = \{(16969 \times 1580) \times (1.30)^2\} = 4, 53, 10,624 \text{ JS}^{-1}$
$L_2 = \{(28289 \times 1620) \times (1.32)^2\} = 7, 98, 51,021 \text{ JS}^{-1}$
$L_3 = \{(45262 \times 1750) \times (1.18)^2\} = 11, 00, 99,815 \text{ JS}^{-1}$
$L_4 = \{(76739 \times 1800) \times (3.5)^2\} = 1711433178 \text{ JS}^{-1}$

Now $E_K = 194, 66, 94,638 / 2$

$$= 97, 33, 47,319 \text{ JS}^{-1}$$

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 7717, 64, 61,505 JS$^{-1}$, whereas the amount of kinetic energy for that entire reach is 97, 33, 47,319 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 and silt than clay. Thus, liquidification of over saturated bank results into slumping, cavitation, rotational slip, subsurface passage way, areal collapse etc.

**Concluding Remarks**

The analysis provides a clear idea about the spatial pattern of leftward shifting of the river over a prolonged time period. The study reveals academic insights into the matter regarding length of the shift gained and lost in vigorous bank slumping menace. On the basis of the shifting analysis, the foregoing fact file can be revealed under the following heads:

i) After the super initial phases of 1917-18, the river made a lobe towards east, though almost with negligible amplitude of curvature during 1929-1930s, which actually culminated during 1970-1971.

ii) Starting from 1970s to 1980s via the years 1973, 1974, 1975, 1977, 1980 mainly the localities like Dhelpurua, Shibganj, Toffi, Charbabapur, up to Laskartola nearer to the Farakka Barrage were in attack and slumping was carried out in almost parallel fashion.

iii) In the next entire decade, the need of maintenance of hydro dynamism and meander cut development with skirting thalweg, the effect was found along Manikchak, Moynapur, Domhat section at the northern part of the river comprising the year marks like 1980, 1981, 1982, 1985, 1986, to 1990s and liaison or off shock effects of lesser propensity was experienced at Panchanandapur, Sakullapur, Khaskol belt which have been in more or less erosion withdrawal in this periods.

iv) The immediate next phase was of the axis top of the meander curve of the river covering localities like Sakullapur, Panchanandapur, Khaskol, Jot Kasturi, Birodhi section mostly starting from 1995 onwards with tremendous severity after 1997, 1998 and 2000 flood effects and continued up to 2005 with a gross rate of 330-450 hectares of yearly land loss associated with 10 to 15 Kms of bank lengths under attacks, 25.40 m of water table and fluctuating 1 m to 2 m in deluge periods. This resulted 1000s of homeless destitute and clandestine calamity refugees during 2000 to 2003.

Thus, the propensity of river oscillation and magnitude of erosion of the river is concerned with the fluvial and morphological modifications, which have created a devastating situation. Until the meander curve denies the main flow of the river (Thalweg velocity) to take such a bend turn to passage out, and turning to a shortest possible path, there will be erosion at places to attain the culminating phase of meander curvature development.

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