Oscillation of meandering Bhagirathi on the alluvial flood plain of Bengal Basin, India; as controlled by the Palaeo-geomorphic architecture

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ABSTRACT

The channel morphometry depends on its planform geometry and the processes operating within its meander belt area. In the wide young alluvial tracts, it oscillates laterally getting supported by variability of water discharge, sediment load, bedrock outcrops, ground slopes, human activities and tectonic influence. Bhagirathi-Hooghly River system is an essential lifeline for the people of southern West Bengal, India, which provides perpetual supply of water for irrigation and human and industry consumption. Although total river reach is experiencing a huge morphometric change followed by lateral shift and bank erosion; the channel stretch that has been taken in this study, has the highest sinuosity and parcels of acute meandering along with the palaeo-channel formations existed on its younger flood plain. The palaeo-channel formations support the fact of Indian plate tilting in the south-eastward direction. The elevation as depicted in the cross-profile made on Digital Elevation Model is casting the sequential changes in the channel path followed by the formation of palaeo-geomorphic architecture. This can indicate potential zones for ground water. Analysis of fluvio-geomorphic scenario can assist trend analysis, so that, this can be taken under consideration while occurring any human intervention in natural free flow.

Keywords: channel morphometry, lateral shift, meandering, plate tilting, flood-plain, palaeo-geomorphic, human intervention.

1. Introduction

Bhagirathi-Hooghly is approximately 260 km long distributary of the Ganges River in West Bengal, India. It is one of the most prominent rivers of South Bengal drawing the westernmost border of Ganga delta. This river has a long history of lateral migration and avulsion. It is believed that the Bhagirathi was the main flow of Ganga, hundreds of years ago. The present channel of the Bhagirathi, with its sacred traditions and ruined cities, marks the ancient course of the river Ganga. The original river Ganga used to flow across the entire north and east India from Uttarakhand (formerly Uttar Pradesh) to West Bengal (formerly Bengal) before the 16th century. Geologists say, before it diverted to the Padma eastward, there might have been two major channels, flowing more or less independently and building the deltaic tract in the part of Bengal: the Ganga flowed through central Bengal and the Teesta through further east of undivided Bengal. Earlier, the Teesta was reinforced by the Mahananda and the Kosi and still earlier, perhaps also by the Brahmaputra before it coursed eastward to the Meghna. These north Bengal Rivers flowed and fell together into the sea, probably through the Meghna estuary. This hypothesis fits in with the historical and mythological evidences, supporting the contention that the Bhagirathi was the main flow of the Ganga in old days.
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Early in the 16th century, the main course of the Ganga shifted eastward to the present Padma. This may have been due to some tectonic changes and natural calamities, leading to rapid deterioration of the Bhagirathi. At Bandel in Hooghly district, the river bifurcated into the Saraswati and the Bhagirathi, alias Adi Ganga beside and below Kolkata. The Saraswati was a major maritime river. A Branch, ostensively a man-made channel at Kolkata, connected it with the Bhagirathi / Adi Ganga. At that time, the main course of the Damodar River used to flow into the main Bhagirathi at a few kilometers north of Triveni. In 1770 AD, following a severe flood, the Damodar changed its course and flowed into the Bhagirathi, about 50 km south of Kolkata, causing a major change in its system. Above the changed confluence point, the Saraswati and the Bhagirathi became extinct and the Bhagirathi flowed along the present course of the Hooghly.

Several inter-related effects which influence the distribution of channel migration are: compaction of fine sediment, tectonic movement and channel gradient. Tectonic movements do not have a significant influence upon the successions unless a preferred direction of tilting is maintained. The Bengal Basin in the northeastern part of Indian subcontinent, between the Indian Shield and Indo-Burman Ranges, comprises three geo-tectonic provinces: (1) The Stable Shelf; (2) The Central Deep Basin and (3) The Chittagong–Tripura Fold Belt. Due to location of the basin at the juncture of three interacting plates, viz., the Indian, Burma and Tibetan (Eurasian) Plates, the basin-fill history of these geo-tectonic provinces varied considerably. This basin lies near the two plate-convergence boundaries: the Himalayan and the Burma Arcs. These arcs are convex toward the Indian plate and override it from the north and from the east, respectively. The fore-deeps of the Himalaya and Burma Arcs reflect the subducting lithosphere under the load of overriding plates. India, with the basin, is thus the foreland of both Himalayan and Burma convergent boundaries with their broad advancing fore-deeps and thrust–fold belts. Along the Himalayan arc, continents have been colliding since the Eocene. The influx of sediment into the basin from the Himalayas to the north and the Indo-Burman Ranges to the east rapidly increased at this time; and this was followed by an increase in the rate of subsidence of the basin. This initiated the Indian Plate to tilt towards south-eastern direction which was a major factor behind the avulsion of many rivers of Ganga-Brahmaputra Delta.

The Bhagirathi-Hooghly River has been facing a number of changes in its branch-off point from parent river Ganga through time mainly due to the oscillation of River Ganga down-stream of Farakka Barrage which was also a consequence of tectonic instability. It made the Bhagirathi-Hooghly River almost abandoned which might have diminished the significance of Calcutta port. To save the port and get all season controlled discharge, 26 mile long Feeder canal was constructed in 1975. This controlled channeling of discharge through feeder canal though could maintain the flow of Bhagirathi, but could not prevent its oscillation. After the lateral shift the new river reach is associated with spatial impressions of the former channel. These channel left-outs somewhere remain as abandoned and somewhere with water being rain fed seasonally or permanently. The spatial meandering pattern does not indicate any east or westward shift of the total river reach rather the reach has patches with varied rates of river dynamism.

2. Study area

This study has been conducted on a fluvio-geomorphological analysis of Bhagirathi-Hooghly River reach from 5 km north of the confluence of Ajay River to 5 km south of Jalangi River confluence on the Bengal basin, India. It has a bank line stretch of about 73 km. The river mainly acts as a border between two districts of West Bengal: Barddhaman and Nadia. The
study area encompasses the meander belt on both sides of this major river of southern part of West Bengal.

![Study area](image)

**Figure 1: Study area**

3. Result and discussion

The relevance of selection of this study area should be elaborated first. Bhagirathi-Hooghly River from its present take-off point at Mithipur is in its almost abandoned status. At the east of Bangabari village, this abandoned channel has been recharged by an artificial out-tracking of a portion of Ganga River water (Feeder Canal). Down-stream of this point, whole of the river experiences several fluvio-geomorphic instability in its path. This makes the river highly sinuous in character. Because of an artificially controlled discharge, though the thalweg swings frequently, it is characterized by a narrow and deep, well-defined, non-braided pattern. The serpentine pattern of flow can be seen all through the basin, though with a variation in magnitude. The sinuosity index calculated for the river from its confluence with feeder canal to Kolkata is 1.51, whereas, this index is 1.73 for the river reach selected for this study. This is the area where the river oscillation can be seen at highest magnitude along with all its palaeo-geomorphological imprints.
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Figure 2: Survey of India topographical

The analysis of the lateral migration of the Bhagirathi-Hooghly River has been carried out with three spatio-temporal satellite data. These are: 1972 Survey of India Topographical Sheets of 1:50,000 scale, 1996 River reach from Landsat TM and 2011 IRS Liss III MSS. Digital Elevation Model of 2000 has also been taken for the analysis of Z co-ordinate across the flood-plain. The river oscillation within the study area has been gone through a comparative study with all these temporal data-sets. In (Figure – 2), point A denotes the confluence of Ajay River and Bhagirathi River; whereas, point B denotes the meeting point of Jalangi River and Bhagirathi River.

Whole of the meander belt area is geomorphologically very active. This north-south flowing river is characterized by acute meandering with all its past channel imprints like cut-off meanders, ox-bow lakes, meander scars, abandoned channels etc. The formation of ox-bow Lakes is very prominent here. They have been formed due to either neck cut-off or chute cut-off. The neck cut off occurs when closest parts of the meander loop become closer and intersects with the upstream side detaching the loop. The chute cut-off occurs due to abrupt formation of cannel connecting the closest part of meandering loop due to locally increased gradient and velocity in the cut-off area. All these former flow paths of the river are very much important in terms of ground water prospect analysis. For the purpose, these cut-offs can be gone through an analysis of the river flow and hence can be arranged by their time sequence.

In this study area, there are mainly two prominent ox-bow lakes. One is in the northern part on the left bank of the river and another in the southern part on the right bank of the river. Both of these existed as the channel path of 1972. So, these ox-bows are the recent major palaeo-geomorphological formations.
In OB1, the ox-bow lake, formed at about 13 km downstream of the confluence of Ajay River, is present as a deep inland natural. The past connection of the ox-bow with the present channel can be identified as the highest ground water potential zone.

Figure 4: morphometric set up built by the river, cross-section OB1a-OB1b

To present a morphometric set up built by the river, cross-section OB1a-OB1b has been drawn as per Digital Elevation Model data, which shows almost same depth of both of the present channel and ox-bow lakes. In that cross-section, O1 is showing the mainland with a comparatively higher elevation; whereas, O2 presents a wide palaeo-channel area i.e. former channel path of 1972. This can have a high ground water potentiality. O3 is the main Bhagirathi River thatweg. O4 again is showing the main land. O5 represents the bank portion of the cut-off inland natural which is mainly practiced by summer paddy crops due to seasonal submergence. O6 is presenting the right horn of the ox-bow. O7 shows the middle
part of the ox-bow which had not been followed by channel anytime in the past. So, this is mainly a stable agricultural zone with older alluvium. O8 presents the left horn of the ox-bow.

**Figure 5:** morphometric set up built by the river, cross-section OB2a-OB2b

In cross section OB2a-OB2b, it can be supported that the ox-bow lake had experienced a series of channel shifts during 1972-2011 to get the present straight path. This assumption is supported by the cross-sectional elevation of the whole flood plain. The land in between O1 and O9 main land (two extremes of this cross-section) is low with a number of narrow channels within it. The range of elevation is low in this section. O2 is showing the left horn of the ox-bow lake width a wide submerged low land left to it. Western portion of the ox-bow core is comparatively stable and of higher elevation. But, eastern part is palaeo in nature. It can be assumed that the left horn after 1972 had frequent changes from east-west trend to almost north-south trend. Due to this, the total land from right horn to present channel (excluding the eastern margins of right horn) was undergone the channel shifting. On the cross-section, the channel of 2011 is having a channel bar developed on it resulting in the bifurcation of the main discharge in to two narrow thalwegs. This channel bar is represented here by O7 bounded by two narrow thalwegs O6 and O8.

In the present channel morphometry within the study area, some meander loops can be supposed to be cut-off. Those pockets of the channel have a very high sinuous character. One is at just south of the northern ox-bow and another is at the north of southern ox-bow lake. These two pockets can be treated as the predicted most active pockets in near future.

In case of up-stream meander (US), the angle if incision for the upper bend (q°) is lower than that of the lower bend (q°). It indicates that the spatial distance between two horns of the lower bend (q°) is higher with a higher proximity to the occurrence of neck cut-off. Whereas; in case of the down-stream meander (DS), the angle of incision is comparatively lower than that of the US meander.
Figure 6: up-stream meander (US), the angle of incision for the upper bend (p°)

So, this bend has lower risk of channel straightening in near future. But, a new trend of increasing sedimentation in the river channel can be noticed just down-stream of the bend. This may act as an obstruction to the natural flow and may enhance the pressure on the left bank of the northern horn of the bend. If such a probability meets the reality, then river straightening can be warmed up, which may result in a huge devastation within the bend core areas.

Figure 7: Development due to river shifting

While analyzing the ox-bow development due to river shifting, it can be viewed that the northern ox-bow lake had been developed because of the southward shifting if the river, whereas; the southern ox-bow lake had been developed due to eastward shifting of the river.
In case of existing acute meander belt in the down-stream (DS), the tendency for future river oscillation of the northern bend is eastward leaving the cut-off on its right bank. So, it can be stressed on the fact that river shifting here will be supporting the assumption of southward and eastward tilting of the Bengal Basin. But, if the whole flood plain stretch of the study area can be analyzed in terms of its palaeo-geomorphic alignment, it can be seen (Figure-7) that, major palaeo-geomorphic features are present in the eastern side of the river flow. It simply indicates a westward lateral migration of the river in past leaving its historic signatures on its left bank. This situation must have happened in remote past, because all these left bank palaeo-impressions can be well-identified in 1970’s Survey of India Topographical sheet of 1:50,000 scale. Hence, these spatio-temporal evidences are not getting synchronized with the fact of plate tilting.

This lateral migration of the river took place with the damage of a huge mass of natural resources, hampered the livelihood of a number of villages and damage of man-made infrastructures. The whole meander belt area is very much vulnerable because, any time due to any tectonic or other morphometric factors, the river can take any of its former paths. But, because of the availability of high fertile land, high agricultural productivity initiates emergence of numerous settlements. To connect those settlements infrastructural set-ups are invariably needed. But, sometimes, geomorphic architecture is ignored in this matter. For instance, south of Jalangi River confluence, a bridge has been constructed on Bhagirathi River, where a bank nudge can be visualized on the left bank of the river. The base of the bridge has been unfortunately constructed on the meander scars of the river. For the sake of the bridge safety, the engineers have implemented the bank protection measures there like boulder pitching along the left bank, but the structures have now been started to be damaged at both sides of the bridge basement. The river has started to encroach towards the eastward former meandering path which is showing an alarming situation for the existence of the bridge. This is only because of the construction of that major connecting road across the river had not taken the river morphology under consideration. Actually, within this study reach of Bhagirathi from Ajay River confluence to Jalangi River confluence, it will be very tough to construct any connecting infrastructural set-up, because this is the most fluvial active zone of the whole Bhagirathi-Hooghly River.

4. Conclusion

The channel pattern of a river depends on its planform geometry and the processes operating within its reach. Traditionally, the channel pattern of a river has been classified into straight, meandering and braiding types. The diversity in the channel patterns is caused due to variability of water discharge, sediment load, bedrock outcrops, ground slopes, human activities and tectonic influence. Tectonic movements change the gradient of a river and modify the valley. This study has dealt with such a long changing fluvial history with high lateral mobility. The increased flushing of the Hooghly, allowed by the construction of the Farakka Barrage, has brought about a considerable increase in the freshwater supply in the Hooghly estuary. The work of Farakka Barrage started in 1962 and ended in 1971. Four more years were needed to build-up the feeder canal and the project were dedicated to the nation on the 21st May 1975. Such a study facilitates to get an overview of the river reach on temporal basis, rather to say, to monitor the instability of the channel. It thus indicates the erosion or bank failure zones as well as depositional or alluvial emergence areas in different time spans. It also imprints past river path through its tone, texture, shape and association factors which also demarcates the areas of high moisture content. The whole river reach is characterized by a change in meandering pattern rather than a total lateral shift. Somewhere, the river is taking
its meandering path whereas in some places the river is becoming straight leaving apart the past meander as detached from its body. So, each bend is on a different stage of meandering cycle. Meandering cycle includes the formation of a bent, increase in acuteness of the bent, acuteness reaches to extreme that the two horns of meander join and the channel becomes again straight, the previous bent stands apart as a meander loop with or without water. These impressions of former channels can be rejuvenated again and cause severe damage to existing resources. So, such a looking back towards historical set-ups of a river, can plot an overall geomorphic scenario of the fluvial platform, so that nature can be taken in mind all the time whenever modifying the existed set-up by human intervention. Management of fluvial systems addresses the everyday conflicts between river dynamics and human investment in the landscape. The proper foundation of protection, and restoration of rivers stands on a geomorphic assessment of the physical condition, sensitivity, and the adjustment process of discreet stream reaches.

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5. References


