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Research Article

MORPHODYNAMICS OF THE MEANDERING RIVER: A STUDY ALONG THE SUBARNAREKHA RIVER OF GOPIBALLAVPUR SECTION, WEST BENGAL, INDIA

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ABSTRACT

Rivers not only represent a vital resource for human activity but they are central to an understanding of geomorphology of most regions. A section of the river Subarnarekha (near Gopiballavpur) is considered for the study on bed and bank morphology associated with patterns of process and channel adjustment. The process-based study of alluvial channel has emphasized an alternative and smaller time and space scale for understanding alluvial channel dynamics.

The sand-bed of river tract is complicated by the effects of significantly changing bed forms. However, the gravel bed of the river is lying below the depth of 1 meter from the top of the point bar sand bed which is often not mobile until discharges approach bank-full stage. The bank morphology reveals flood signatures of past events. The depositional activity of over bank flow on the floodplain is very different among the riverine system. The class of extreme events determines channel capacity, affecting channel pattern and more frequent events, although at times widely separated in time, controlled bed load movement and bed form adjustment.

Variation of grain size is recorded from the outer bank to inner bank at the meandered section of Subarnarekha. Sand splays are significant feature on the over bank deposits particularly at the section of meandered banks. Bank margin cliffs are found on the older depositional bars at the curvature of the channel. All these modification of channel floor and channel bank are product of bank full discharge in the occurrences of floods.

Repeated field survey, sediment grain size analysis, measurement of geomorphic features, satellite image analysis and analysis of discharge data reveal the above features of dynamic alluvial channel.

Keywords: *Morphodynamics, Channel Dynamics, Meander Bank, Sand Splays, Bank Margin Cliffs*

INTRODUCTION

Meandering rivers have been subject to study or analysis their forms, hydrodynamics nature and also the probable causes and consequences of their movement (Blum *et al.*, 2005; Bridge, 2003; Kim *et al.*, 1999). In this context remote sensing data is a key source of information about studying and monitoring the river shifting or migration. Remote sensing and GIS have enhanced the idea to analyze channel platform, geomorphic changes and bank line erosion from several sources of data (Yang *et al.*, 1999; Sharma and Basumallick, 1980; Sharma *et al.,* 2007). Generally, the channel pattern of a river has been classified into straight, sinuous, meandering and braiding types (Leopold and Wolman, 1957).

The distance between two points on the stream measured along the channel is divided by the straight distance between those two particular points is called the sinuosity ratio (Brice, 1984; Ebisemiju, 1994). The diversity in channel patterns is influenced by the changing nature of water discharge, sediment load, topographic slope, human activities etc. (Aswathy, *et al.,* 2007). Hydrodynamism is key factor for controlling the other parameters like micro-geomorphological features, sediment grain distribution etc. The sedimentological structure of a point bar margin profile in a meandering river can help us to explore and detail studies on modern sedimentation (Bridge, 2006; Gibling, 2006; Xue, 1986; Kolla *et al.,* 2007; Willis and Tang, 2010).

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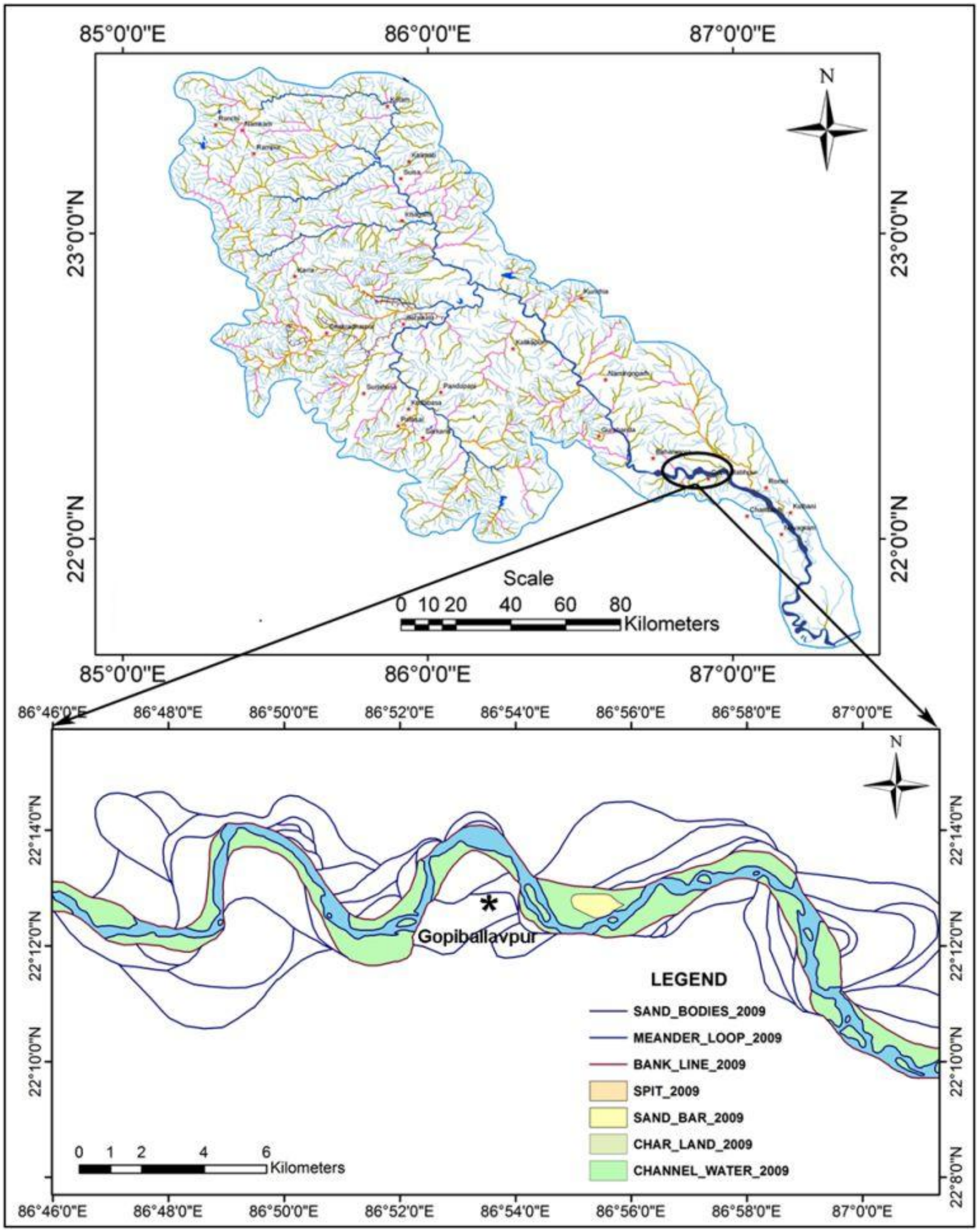

Figure 1: An overview map of the study area showing the channel (Subarnarekha river) morphology with paleo meander loops

The present study section of the Subarnarekha River is subject to analysis of hydrological and geomorphological parameters in the meandering part of Gopiballavpur section (Figure 1). There are some paleo meandering signatures in the both side of the river banks. Several geomorphic signatures are found in a small stretch. Variations in the sediment grain distribution in the different erosional and depositional geomorphic platforms are being studied. Hence, an attempt has been made to study the nature of channel migration within a short term period from 2006 to 2010.

MATERIALS AND METHODS

The small scale image data of IRS P4 LISS III acquired in January 2006 and 2010 respectively are collected for temporal analysis. Both the images are analyses through ArcGIS software and the channel is digitized depending upon the tonal variation of the image. Finally, channel pattern of two selective years are analyses and the channel geometry is calculated. Channel geomorphic signatures like pool and riffle positions are identified. Paleo meanders are identified and digitized based on the satellite images and Google earth images of various years.

Channel water velocity and depth of the river bed in the selective area are carried down through digital current meter and staff respectively with GPS location specific spatial variation. Other geomorphological information is acquired during field work for assessing various pattern of formation and spatial variation of deposition on channel bed.

Geomorphological works, sedimentolgical analysis have been done through layer wise sample collection of two specific pint bars near Nayabasan and Dharmapur villages. Samples are dried up and sieving in thirteen sieve set of different phi scale. Sediments are weighted through digital weight machine and are calculated in percentage of distribution in each sieve set. Necessary statistical calculations are done by the SPSS software. The impacts of human encroachment over channel have been observed during field work.

RESULTS AND DISCUSSION

Hydrodynamics

In this meandering section of the river the nature of hydro-dynamics is subjected to high fluctuations of water level due to the seasonal diversity of rainfall. During monsoonal rainfall the Subarnarekha River carries bank full water discharge with much more sediment load, but in the lean phase of summer and winter the river carries only a minimum amount of water discharge with almost sediment free water.

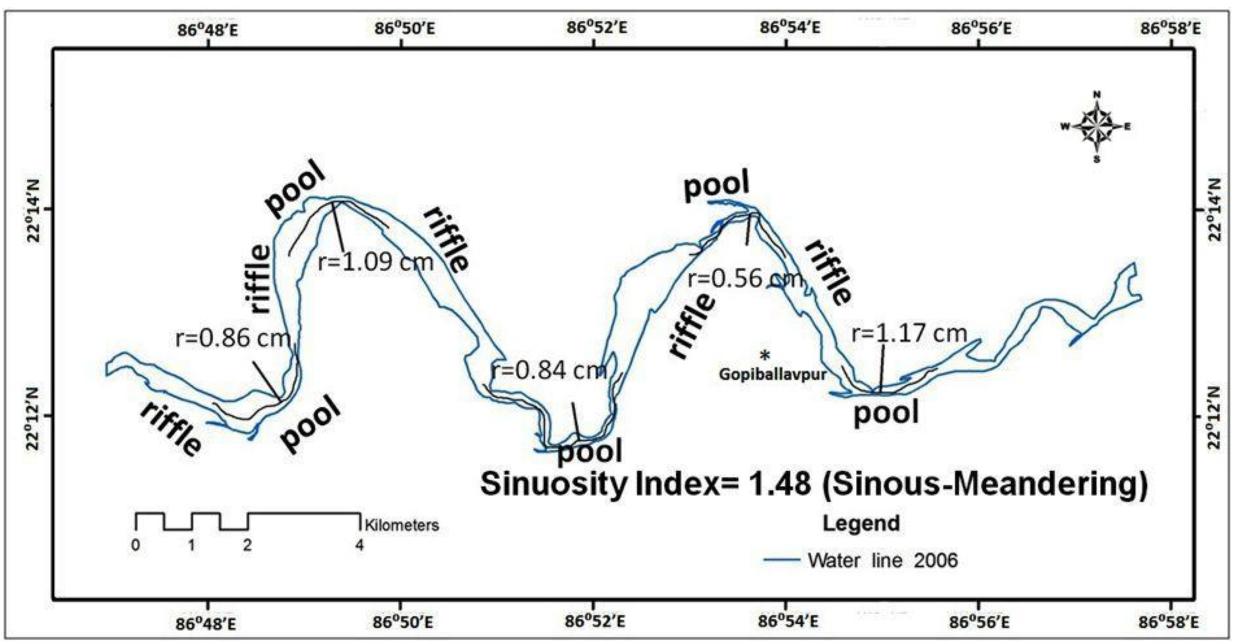

Figure 2: The position of pools and riffles (2006) in the meandering stretch of Subarnerekha in the study section

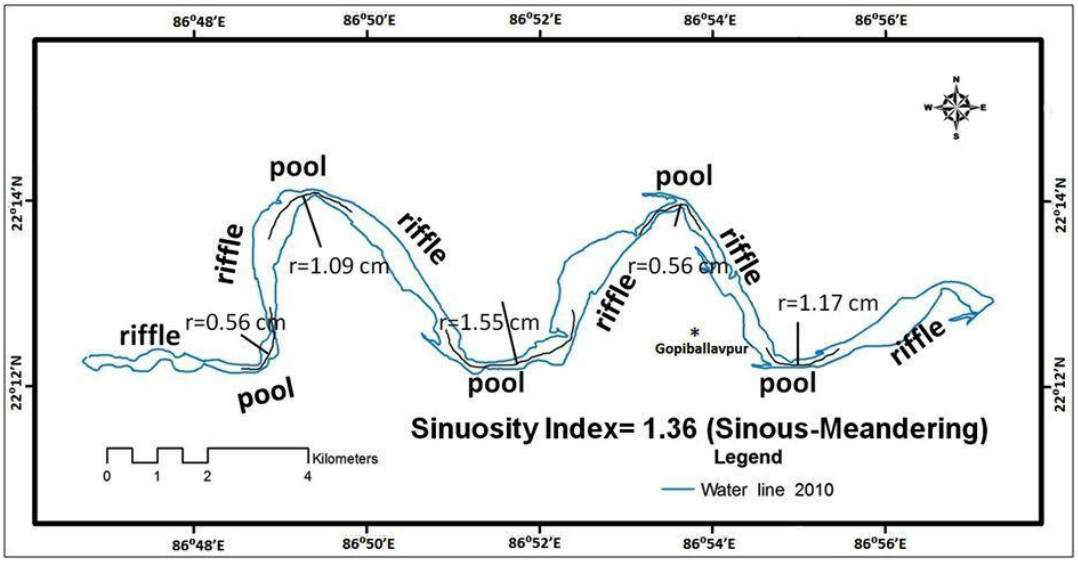

Figure 3: The position of pools and riffles (2010) in the meandering stretch of Subarnerekha in the study section

This section is characterized by meanders, with successive pools and riffles condition of channel. The changing natures of meanders are caused by the hydrodynamics of river itself. In both, the year of 2006 and 2010 five pools and riffles situated, but the radius of circles of roundness (r) of the pools changed in first three pools (from the upstream) sections and the radius of circles roundness (r) for remaining two pools remained unchanged (Figure 2 and 3). In case of riffle sections of streams there was only slight change in the first riffle (upstream) in respect of 2006 to 2010. In the pools position of channel water depth and velocity both are high in respect to riffle positions. There is a positive correlation (0.67) between both these parameters (Figure 4). For that reason there are also significant changes in erosional and depositional signature in river bed and over point bar sections. Near pool positions there are more erosional activities that happen during lean phase and more depositional activities are observed over point bars during bank full discharge of monsoonal flood.

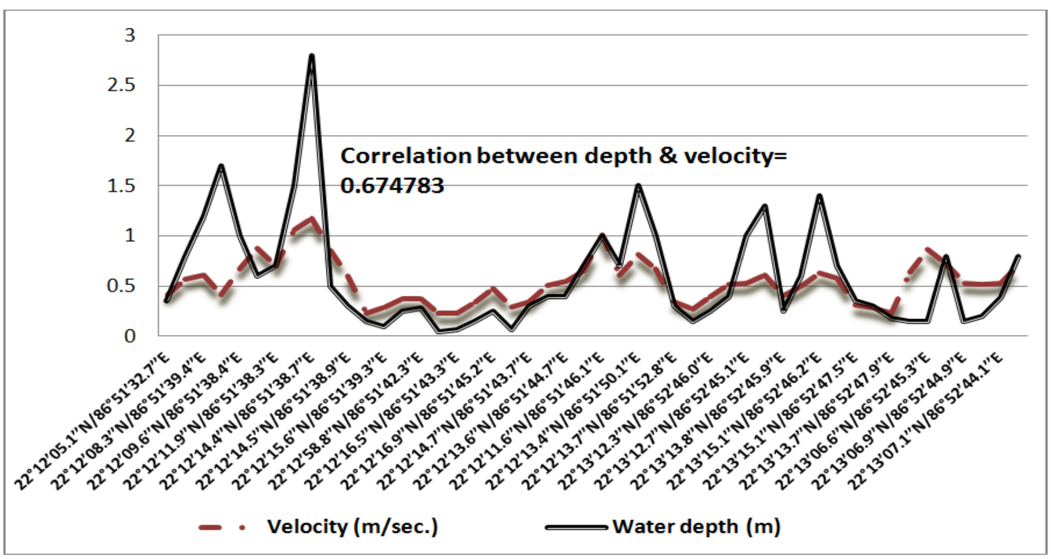

Figure 4: Spatial variation of water depth and current velocity (October, 2012) in the meandering stretch of the study area

Meandering Nature

The study section of the Subarnarekha River is in near meandering stage in the sinuosity scale with index value of 1.48 according to 2006 image data and 1.36 in 2010 image data (Figure 2 and 3). This nature is going through the sinuous to meandering stage. During 2006 the sinuosity index was much more than 2010. Basic change in the meandering course is in the river stretch near Dharmapur village (Figure 5). After 2006 there was a significant hydrogeomorphic change in the river course caused by the flood event of 2007. In this year the significant erosional changes occurred in the point bar section in the right bank margin of Subarnarekha. Near the downstream section of bridge there was also a significant change in the river course. In all the above mentioned cases the more complex river course has been found with 1.48 value of sinuosity index (Figure 2).

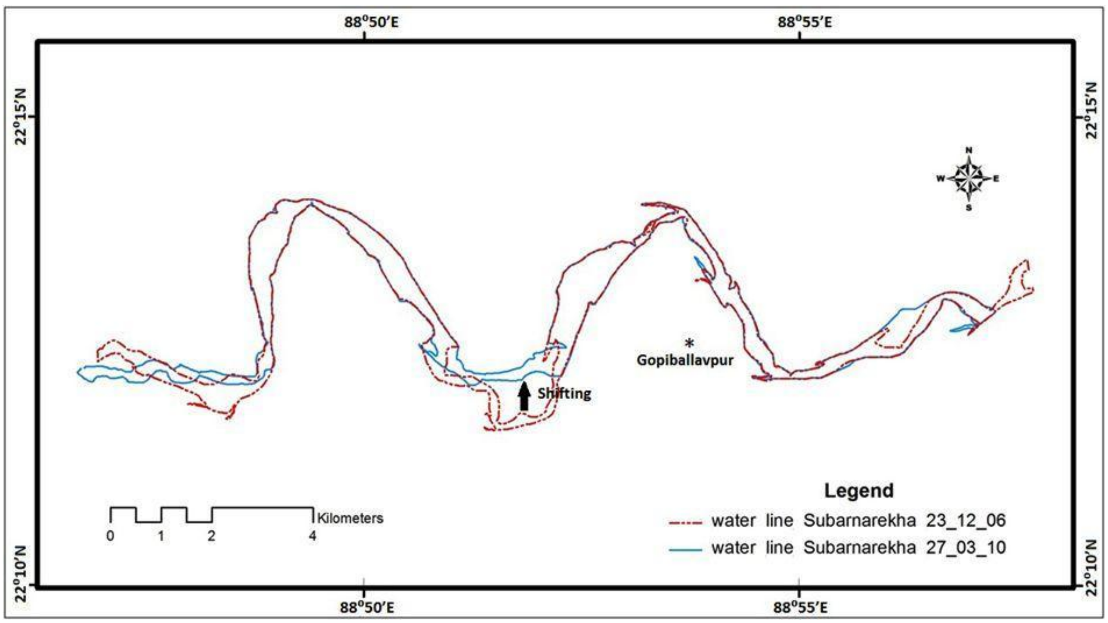

Figure 5: Shifting of the river course in the study section during 2006 to 2010

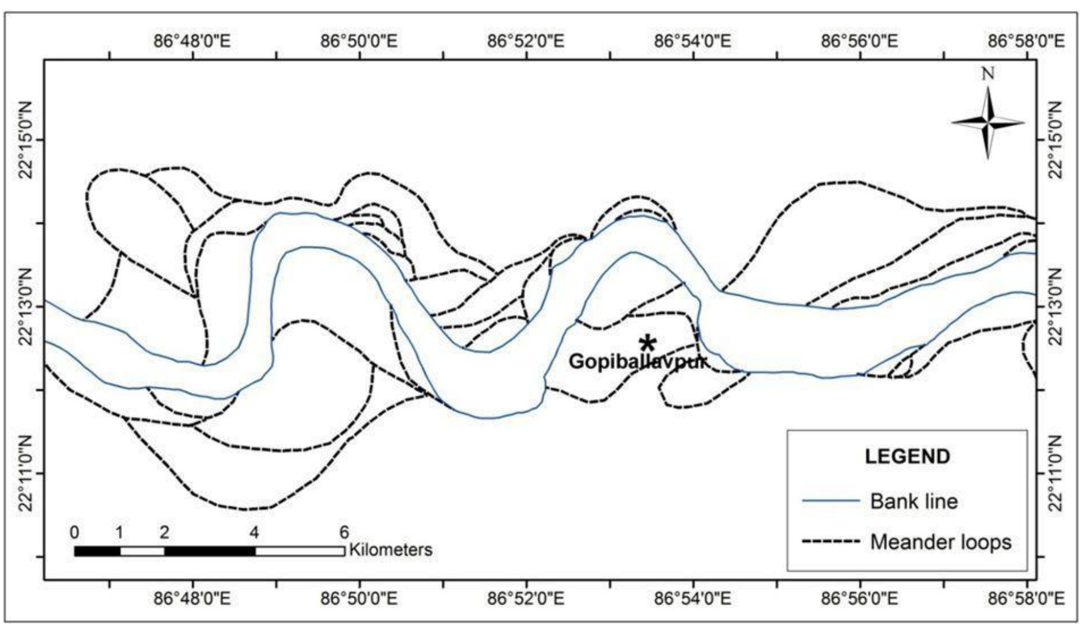

Figure 6: Position of the meander loops in the study area

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There are also a several past fluvial signatures in the section of river course that is found in the image data. These paleo meandering channels are the significant record of the past meandering channel migration that was going on throughout the temporal span.

Another observation of the river migration is also recorded in the left bank that is comparatively more active than the right bank (southern bank) of the river. The paleo meandering channel was migrated with the average horizontal stretch of 5 km (Figure 6) along the course of this river under study.

Fluvial Hydrogeomorphology

The nature of hydrodynamics and meandering pattern of the stream is influenced by the micro and macro geomorphological signatures of fluvial hydro systems.

These macro and micro geomorphic units are identified and related analysis is carried out through seasonal field visit, particularly per-monsoon and post-monsoon seasons (Table 1, Figure 7 and 8) along the river course of selected section.

All the macro and micro geomorphic units are the response to the interaction between fluvial hydrodynamic behaviour and the existing geomorphic units of the river course.

Table 1: Position of various micro and macro geomorphic units with their forming agents

Geomorphic units	**Nature**	**Position in**		**Formed agents**	**Season of field work**
Point bar	Macro geomorphic units	Left bank	Right bank	Fluvial action in meander section	Pre and post monsoon
Sand splays	Macro geomorphic units	Left bank	Right bank	Storm flood	Pre and post monsoon
Levee	Micro geomorphic units	Left bank over point bar		Storm flood	Post monsoon
Desiccation cracks	Micro geomorphic units	Left bank over point bar		Sudden storm flood	Post monsoon
Mud balls	Micro geomorphic units	Left bank margin of point bar		Storm flood	Post monsoon
Gravels	Micro geomorphic units	Left bank margin of point bar		Storm flood	Post monsoon
Ripples	Micro geomorphic units	Left bank over point bar		Storm flood	Post monsoon
Scouring pools	Micro geomorphic units	Left bank over point bar		Storm flood	Post monsoon

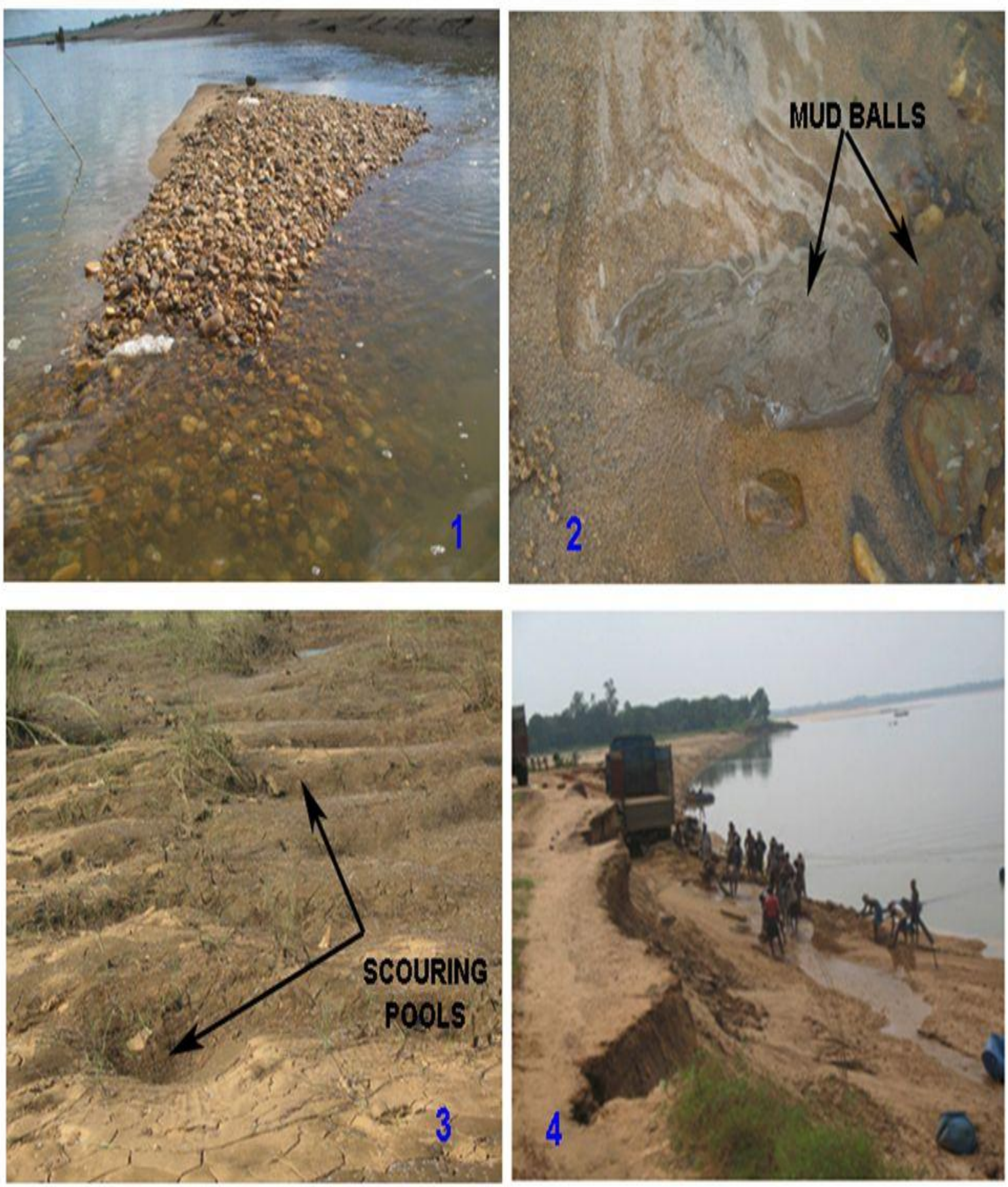

Figure 7: [1] Deposited gravels in the right bank margin after the storm flood; [2] Circular to elongated mud balls are deposited in the pool position of the channel after storm flood; [3] Scouring pools are formed over the point bar due to high magnitude flood; [4] Sand mining activities is going on in the pool position of the river and accelerated the progressive bank failure

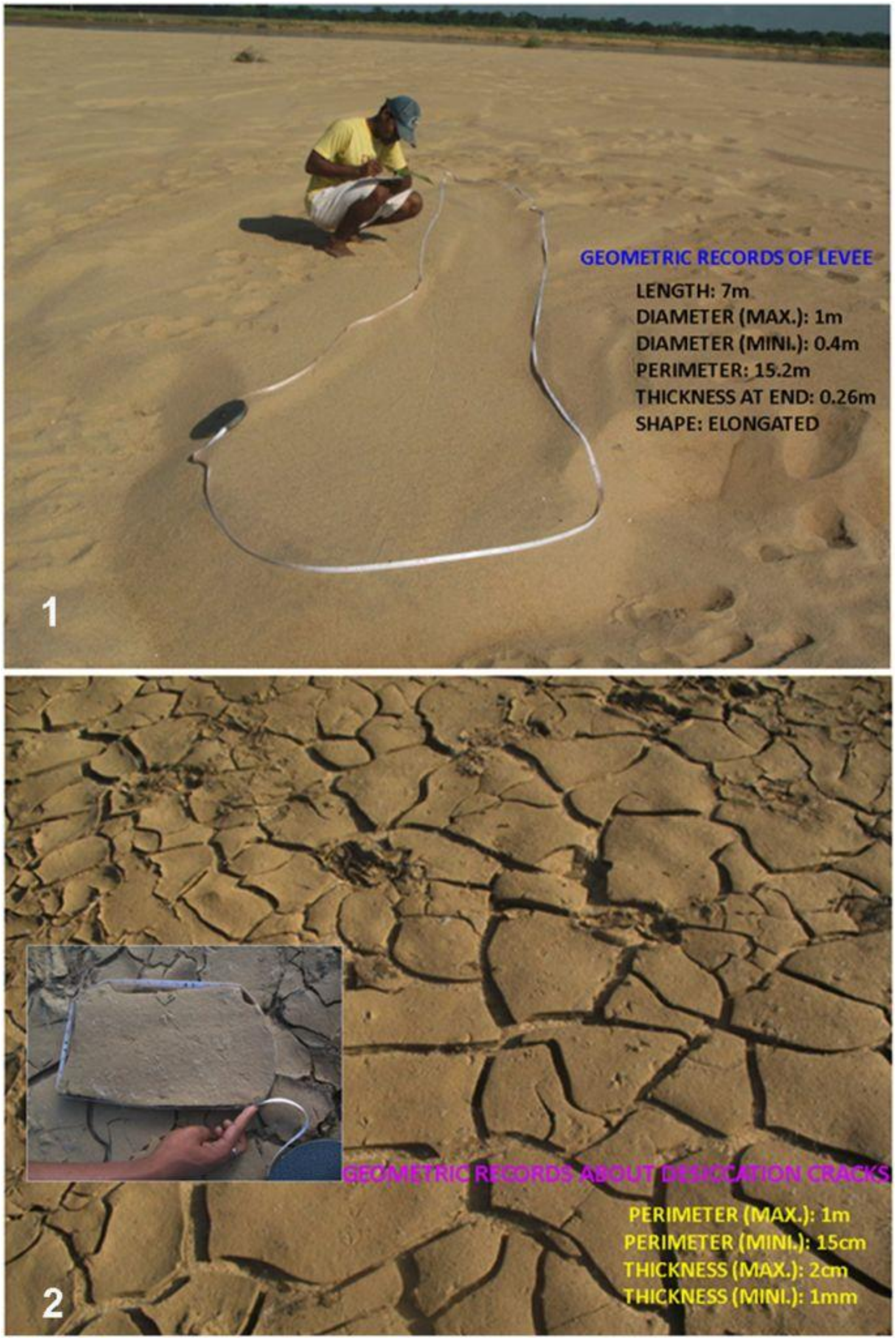

Figure 8: Micro Geomorphic signatures over the point bar in the right bank margin with their geometric record [1] Levee formed by the fluvial activities; [2] Desiccation cracks formed after the solar heating of settled sediment

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Sediment Structures

The sedimentological variation in the point bar sections are the most important signature of the past fluvial dynamics, specially the storm floods. In every position of the channel there is a footprint of the water energy. In the channel bed or over point bars or in sand splays every where the sedimentological variation of grain size is found according to the changing energy level of the river section in the study area. In the channel margin over point bar there are coarser to medium size sand and it is again changed into finer in the bank margin side. In the extreme bank margin site there is the deposition of silt and clay in the sand splays. The same kind of distribution also happened with more coarse sand in channel margin and that gradually changed towards finer with the increasing distance from the channel margin. Over the river bed there are also the textural variations of grain distribution and that was influenced by the space and position of the channel. In the pool position, outside of the curvature, the coarser to very coarser sands along with gravels and pebbles are found. These gravels are also found in the marginal section of sand splays, when the storm energy flood current transported them into this area.

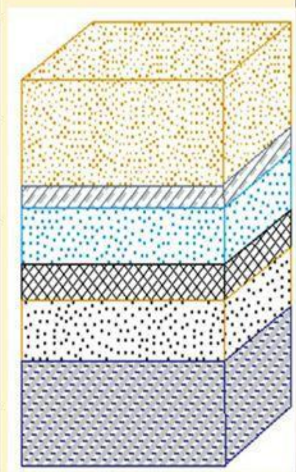
Lithological layers	Thickn-ess (m)	Material content	Colour	Dominated grain size	Dominated Phi (φ) No.	Graphical structure	Photo of that profile
1^{st}	0.50	Medium to finer sand	Whitish Brown	425-250 micron	+1to +2φ		  
2^{nd}	0.08	Finer sand with alluvium	Brownish grey	250-150 micron	+2 to +3φ		
3^{rd}	0.25	Coarser sand	Yellowish grey	500-150 micron	+1 to +3φ		
4^{th}	0.20	Medium size sand with nodules and gravels	Yellowish brown	3.35 mm	-1.75φ		
5^{th}	0.25	Medium size sand	Yellowish brown	450-75 micron	+1.25 to +3.75φ		
6^{th}	0.60	Finer sand with placer deposited strip	Blackish	500-150 micron	+1 to +2.75φ		

Figure 9: Sedimentological analysis of a profile in the recently deposited point bar section (near Dharmapur)

Table 2: Statistics of the sediment grain size distribution of the sediment profile of point bar (near Dharmapur)

Parameters	1^{st} layer (top)	2^{nd} layer	3^{rd} layer	4^{th} layer	5^{th} layer	6^{th} layer
Skewness	2.21	2.11	2.22	1.62	1.71	1.23
Standard deviation	40.01	30.87	21.43	22.48	22.17	22.84

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The sedimentological structure of the point bar section is very diverse in character. We have selected two point bars drapes in the channel margin profile for detailed sedimentological analysis. There are six different layers in a profile position of Dhamapur section and they are significant with their variation in sedimentological characteristics. In the 4th layer from the top there is a signature of storm flood with medium size sands, nodules and gravels that are deposited with 20 cm thickness and having -1.75Φ unit of grain size. Beside that all the layers are composed with course to finer sand with variation of thickness and phi scale (Figure 9). But in another point bar section of the left bank side (near Nayabasan) there is eight different layers in a profile pit. Boulders and nodules have been found in the 8th layer (from the top) of the profile. In this profile there is a dominance of silt and finer sand along with coarser to medium size sand (Figure 10). The standard deviation value is more (40.01) in the 1st layer (Dharmapur) and minimum (21.43) in 3rd layer, but the skewness is more (2.22) in 3rd layer and minimum (1.23) in 6th layer. The skewness values are almost same in first three layers (from top 1st layer 2.21, 2nd layer 2.11 and 3rd layer 2.22) and deviated in last three layers (4th layer 1.62, 5th layer 1.71 and 6th layer 1.23) respectively (Table 2).

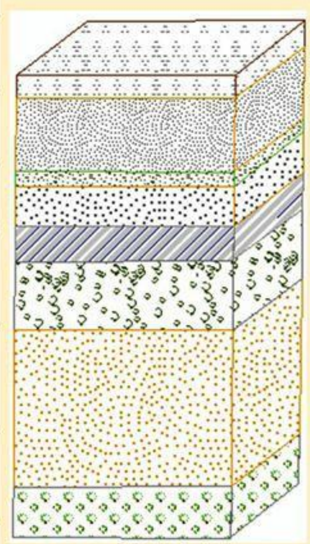
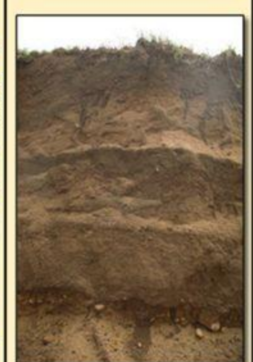
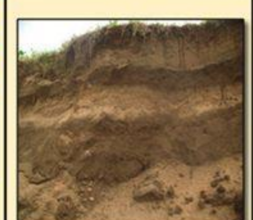
Lithological layers	Thickness (m)	Material content	Colour	Dominated grain size	Dominated Phi (φ) No.	Graphical structure	Photo of that profile
1st	0.3	Younger silt	Warm Brown	125-38 micron	+3 to +4.72φ		 
2nd	0.85	Finer sand	Yellowish grey	425-125 micron	+1.23 to +3.74φ		
3rd	0.15	Silt with finer sand	Brownish grey	150-38 micron	+2.74 to +4.72φ		
4th	0.45	Finer sand	Whitish brown	250-75 micron	+2 to +3.74φ		
5th	0.4	Silt	Blackish brown	75-38 micron	++3.74 to +4.72φ		
6th	0.8	Coarser sand with nodules	Yellowish gray	3.35-2.36 mm	-1.74 to -1.24φ		
7th	1.8	Moderate to coarser size sand	Grayish	1.7 mm-850 micron	-0.77 to +0.23φ		
8th	0.6	Boulders with nodules	Yellowish grey	3.35 mm	-1.74φ		

Figure 10: Sedimentological analysis of a profile in the older deposited point bar section (near Nayabasan)

Human Encroachment Over River

In every society the civilization took place near the river oriented places and the present developmental activities are going on depending upon the nature of river. In case of Subarnarekha River there are also several types of human intervention over the natural course of the river. Among many types, sand mining (Figure 8 [4]) and cross spurs and construction of embankment are directly intervening the natural flow system of the river. An embankment constructed by lateritic boulder obstructed the natural flow of the river in the left bank margin close to Dharmapur.

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The sand mining activities is going on in the both side of river course (upstream and downstream). There are mechanized and manual systems of sand mining process degrading the natural course of the river which in other way influences over the channel margin point bars and river banks.

Conclusion

Like other rivers of tropical region the Subarnarekha River is going through shifts its course in very recently and also abandonment of the meander loops by neck cut-off or migration in gradual way. The recent channel migration on the pool positions are mainly related to erosion in the one bank and gradual sediment deposition in the opposite bank. The minimization of the sinuosity index value in respect to 2006 in 2010 is mainly due to the storm flood event and related erosion and depositional processes. For that reason the circular radius are changed, but the riffle position are remain almost same in the study years. The micro geomorphic units are regularly changed with the seasonal flood and flow dynamics. The sediment deposition is fully controlled by the interaction between water discharge and material grain size. In the point bar section the gravel dominated layer is the significant of the past storm flood dominated energy. Finally, the human encroachment in the river course through embankment construction, bank protection wall or cross spurs construction, sand mining in unscientific ways have accelerated the channel shifting.

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