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Process dynamics and controls in two partially-confined rivers of upper Brahmaputra plain

Nabajit Hazarika, Apurba Kumar Das
School of Sciences, Department of Environmental Science, Tezpur University, Tezpur 784028, Assam, India
apurba@tezu.ernet.in

ABSTRACT

This work quantifies channel processes in two partially-confined rivers of Upper Brahmaputra plain, namely, Gai and Simen and explores their controls. To achieve the objectives this study utilises RS-GIS, rainfall data, seismic data and field observations. Gai migrated back and forth within an extent of 5 km depicting a swinging migration pattern throughout the study period. Simen in its downstream reaches migrated eastward continuously during the study period resulting in river shortening and change in confluence point with Brahmaputra. A reversal in the rate of erosion and deposition is observed in the recent decades with deposition being more dominant. We analyse rainfall regime, seismicity and anthropogenic intervention to examine the dynamic basis of observed changes. Rainfall regime which is a major control of surface runoff did not show any significant change in the total and seasonal amount. Seismicity, another influential stimulus of geomorphic changes shows an overall increase. Complete evaluation of seismicity as a control of sediment dynamics requires detailed measurements across a range of timescales for which the technology and data is missing in this region making it difficult to specify the role of seismicity. Further, increase in seismicity is a global trend which is generally attributed to enhanced capacity of detection. The nature and spatial distribution of the observed geomorphic changes clearly indicates dominance of anthropogenic control in the observed process dynamics of these partially-confined rivers. The present work provides a systematic documentation of geomorphic controls from a data scarce region.

Keywords: River dynamics, erosion-deposition, Brahmaputra plain, Anthropogenic influence, Gai and Simen river.

1. Introduction

Planform metamorphosis takes place in response to changes in intrinsic geomorphic thresholds (Schumm, 1979) and is a world-wide phenomenon. These changes either in a cycle or a system in dynamic equilibrium are attributed to external stimuli such as climate change, tectonic activity, isostatic adjustments and influence of man (Schumm, 1973). Upper Brahmaputra plain is drained by several tributaries and sub-tributaries of Brahmaputra and presents an active fluvial environment. The rivers are flooded annually and bring about large geomorphic changes effecting the population in floodplains and jeopardising the flood control measures. Studies on planform dynamics from Brahmaputra valley have rich tradition and a large literature is available in scientific repositories (Das et al., 2012; Goswami et al., 1999; Sarkar et al., 2012; Sarma and Phukan, 2004; Sarma, 2005) but, there is rarely any, focusing on controls of these dynamics. This work quantifies channel processes in two partially-confined north bank tributaries of Upper Brahmaputra namely Gai and Simen and explains the controls for the observed process dynamics. These two tributaries of Upper Brahmaputra are undergoing accelerated geomorphic changes in recent decades and are often in news for flooding, sand deposition and other associated fluvial hazards. The work derives its motivation from the simple thought that -"knowledge of changing river channels can assist in relaxing the paradigm lock existing between the managers/stakeholders and researchers analyzing changes in river channels" (Gregory, 2006).

2. Study Area

The rivers Gai and Simen are situated ($27^0$15'0"N-$27^0$57'16"N latitude and $94^0$12'18"E-$95^0$30'0"E longitude) between the hills of eastern Himalayas and the river Brahmaputra (Figure 1). The valley that these rivers drains is sandwiched between Himalayan Frontal Thrust and the *Patkai* Thrust and is tectonically active (Lahiri and Sinha, 2012). The unique physiographic setting of the region plays a significant role in controlling the river processes. The catchments, both in the mountains and the plains, experience heavy rainfall during the monsoon season. The annual rainfall of the area ranges from 2600 mm to 3200 mm with July as the rainiest month. On an average, there are about 200 rainy days in a year with rainfall 3.5 mm or above. The rivers are flashy and regularly shift their course causing erosion and deposition.

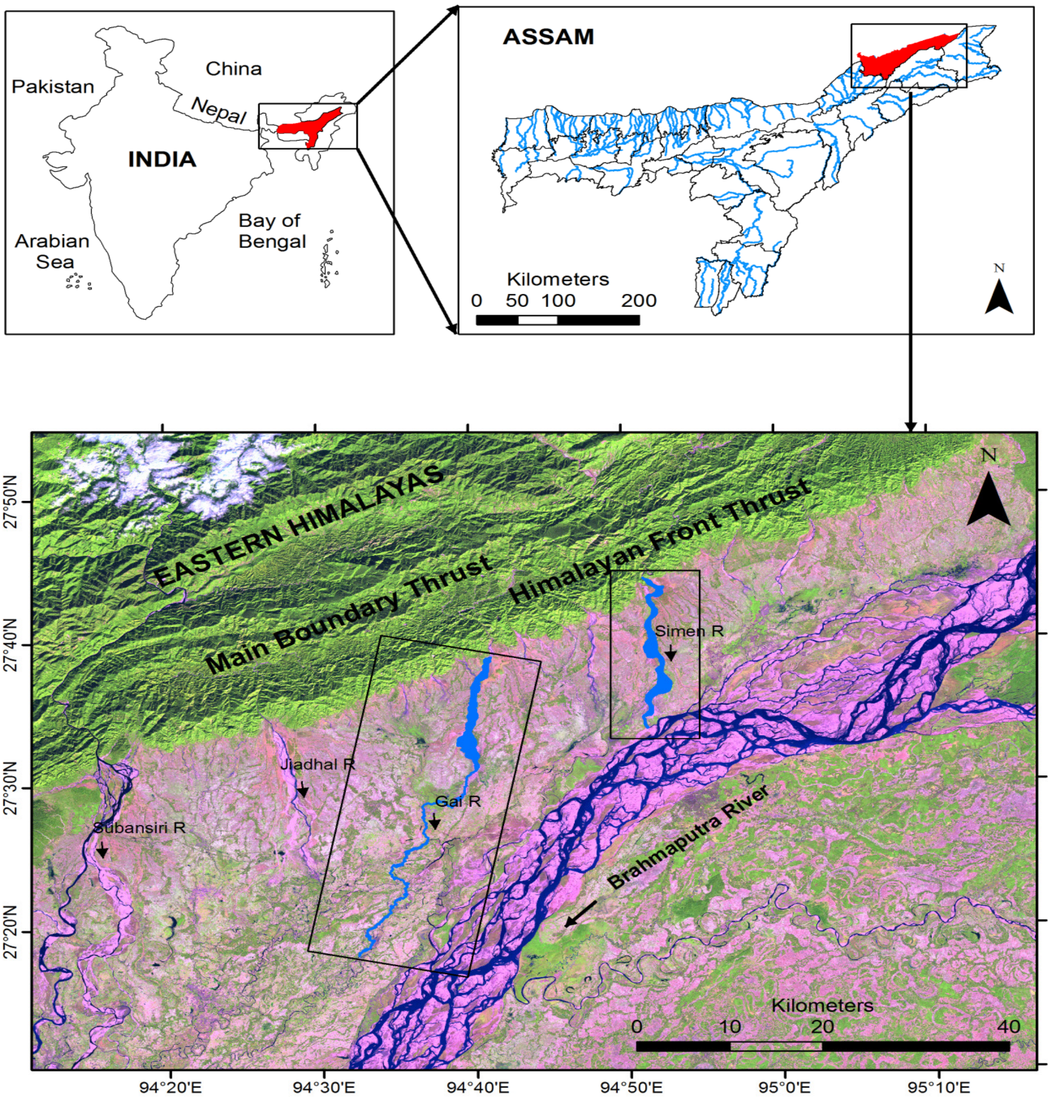

Figure 1: Location map of the study area and the studied stretch of two rivers Gai and Simen.

3. Methodology

3.1 Riverine processes

Historical images, topographic maps, aerial photographs, and satellite images for different time periods serves as a good source for reconstructing river movements, especially for determining lateral channel change and erosion-deposition processes (Lawler, 1993). Use of these data sources with GIS technique is a well-established and an effective tool (Winterbottom, 2000; Roy and Sinha, 2007; Sarma et al., 2007; Kummu et al., 2008; Thakur et al., 2012; Das et al., 2012).

In this work, river processes in the form of lateral channel migration and erosion-deposition for a period of 40 years is quantified. Topographic maps collected from Survey of India, orthorectified Landsat images of the dry periods (lean season) form USGS are utilized after standard image processing (in ERDAS Imagine 11) to study and quantify river processes in GIS environment (Arc GIS 10). The dataset utilized in this study is presented in Table 1.

Table 1: Dataset utilised in this study

Data	Path/Row	Resolution/Scale	Year	Source
Landsat MSS	145/41	60m	1973	Landsat.org
Landsat TM	135/41	30 m	1990	USGS[a]
Landsat ETM+	135/41	30 m	2000	USGS
Landsat TM	135/41	30m	2010	USGS
Topographical Map		1:50000	1969-1970	SOI[b]

[a]United States Geological Survey; [b]Survey Of India

The banklines of the two rivers for the years 1970, 1990, 2000, and 2010 are delineated with the help of visual interpretation as well as digital image processing technique including contrast stretch, crisp, image filtering, different band combinations and image subtraction. Banklines for different periods are overlaid in GIS platform for measuring the lateral channel movement. The studied river stretch is divided into equidistant segments and the highest shifts in these segments are recorded for the three rivers. The total movement of the banklines during a period is divided by the number of years elapsed between two successive observations to calculate the rate of river migration.

For quantification of erosion and deposition the vectorized banklines are overlaid for different periods. The intersecting banks are vectorized as polygons for erosion (where the river migrated into a new position relative to the older channel) and for deposition (polygons for previous position of the river) in each segment. Average rate of erosion and deposition is determined by dividing total erosion/deposition by the number of years elapsed between two successive observations (Goswami et al., 1999).

3.2 Climate change

As a cue to climate change estimation of changes in rainfall pattern is carried out. Monthly rainfall records of 30 years for two stations viz., Lakhimpur and Pasighat and 20 years for Dhemaji (during 1980-2012) from India Meteorological Department (IMD) are utilized to understand if there is any perceptible change in rainfall which may lead to alteration in the hydrological regime in these rivers. Trend analysis for annual and seasonal (monsoonal) rainfall is performed to detect temporal variation.

3.3 Tectonics

Effect of tectonic activity on riverine processes is assessed by utilizing the Earthquake (EQ) data from Advanced National Seismic System (ANSS), USGS. Data from ANSS is collected for all the EQ events from 1950-2014 of magnitude 3.0-8.6 within a 500 km radius of the study area. The data is sorted and arranged in MS Excel based on magnitude and year of occurrence. Total number of events of a particular magnitude range in each year is plotted and trend analysis is carried out to detect changes in frequency of EQs of different magnitude in and around the study region which might impact the river morphology and its processes.

3.4 Anthropogenic role

To determine the anthropogenic role in process dynamics of the river, Topographical maps, Satellite images, secondary data from Embankment and Drainage department (Govt. of Assam) and field observations are utilized. Embankments and bridges are mapped using historical images for different periods. Transect walk along the two rivers are carried out for ground verification of identified anthropogenic interventions and all the features that can hinder the natural river regime are enlisted. Places along the bank of the rivers which are non-communicable because of absence of road or damaged bridges are studied using high resolution Google Earth images for verification of anthropogenic interventions in such places. A systematic listing of all the man-made structures to analyze their role in riverine processes is performed and interviews with local people are also conducted randomly to understand the riverine processes pre and post-construction of engineering structures.

4. Results and discussions

4.1 Lateral channel migration and erosion-deposition

We recorded lateral shifts in the channel banks and calculated the rates for both the river for different periods (Table 2). The trend analysis of river bank migration shows that there is an increase in the tendency to migrate as evident from Figure 2.

Table 2: Rate of migration (km/yr) of Gai and Simen river in different periods of study

River/Period	1970-1990	1990-2000	2000-2010
Gai	0.62	1.74	1.74
Simen	0.70	0.57	0.90

Shifts of order, as high as approx. 5 km, are observed in the middle reaches of Gai river. The pattern of shifts reflects that these are of avulsive nature as the entire river took a new course within these segments. Gai river migrated back and forth within an extent of 5 km depicting a swinging migration pattern throughout the study period. Simen river migrated eastward continuously during the study period by virtue of confluence migration in the downstream reaches. Confluence migration has led to shortening of the river length as the valley is narrow towards east and the river travels a less distance to reach its confluence with Brahmaputra (Figure 3). The river during 1970s travels a length of 68.5 km before falling into the Brahmaputra but reduced to 45.96 km in 2010. Changes in the rate of erosion and deposition are remarkable (Table 3). Deposition emerged as the dominant process in the recent decades indicating a reversal in the process dominance in both the rivers (Figure 4).

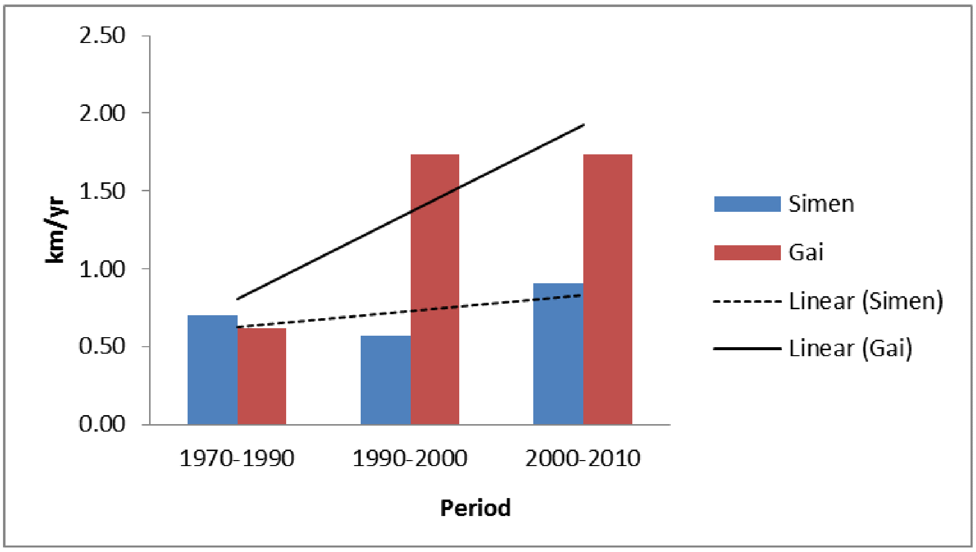

Figure 2: River migration showing an increasing tendency in both the rivers.

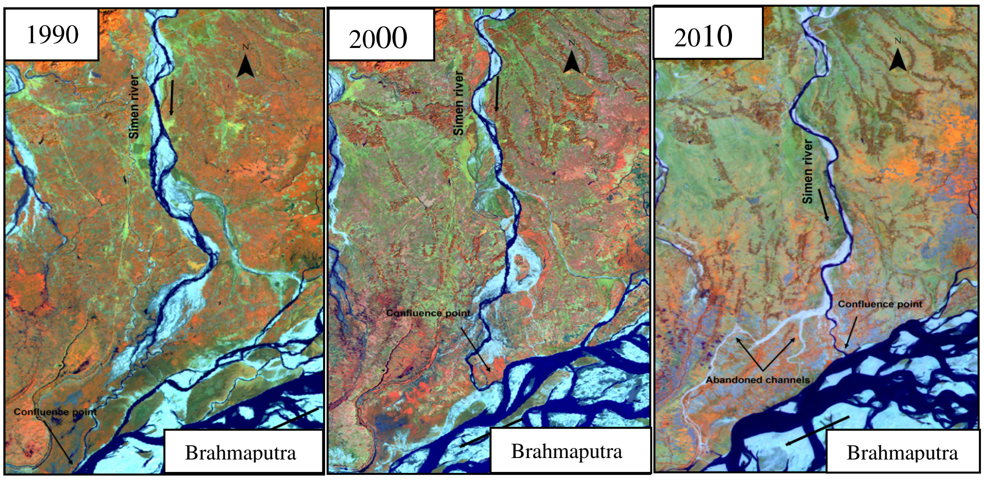

Figure 3: Confluence migration and consequent shortening of river length in Simen river during study period.

Table 3: Annual average rates (ha/yr) of erosion and deposition in studied rivers

River	Process	1970-1990	1990-2000	2000-2010
Gai	Erosion	35.97	43.16	33.40
	Deposition	16.48	36.11	34.08
Simen	Erosion	67.48	46.14	34.81
	Deposition	24.21	77.42	94.76

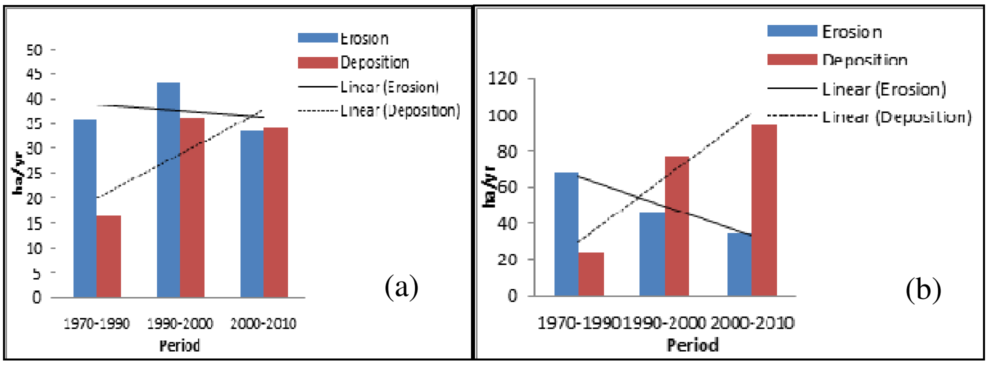

Figure 4: Trends of erosion and deposition in (a) Gai river and (b) Simen river during1970-2010.

4.2 Assessment of controls

The characteristics and behaviour of alluvial river channels reflect the integrated effects of a complex set of controls that include catchment geology, physiography, climate, hydrology and sediment supply (Tooth et al., 2002 and references therein). Climate change is a primary driving force for morphological and process changes in alluvial rivers (Yao et al., 2011; Ollero, 2010). It may modify the characteristics of runoff, changing the regime, frequency and magnitude of floods (Knox, 1993; Feng et al., 2011). Changes in the intensity of precipitation, its total amount and its temporal distribution can directly control runoff and hydrology of water flows (Kiss and Blanka, 2012). Hydrological response of a river basin is defined by the production of runoff against a given rainfall, which in turn is characterized by soil characteristics and basin geomorphology (Jain and Sinha, 2003). In absence of discharge records the precipitation data provide an indication of the varying nature of potential runoff (Winterbottom, 2000). Therefore, in this work effect of climate change on the studied riverine processes is assessed by analyzing the rainfall regime of the area which could bring about changes in the hydrology of the rivers driving process changes.

Another important stimulus that could bring about large surface modifications and influence the process dynamics of the rivers is tectonic activity. Neotectonic deformation is an important control on fluvial processes, directly through its influence on channel slope (Schumm and Khan, 1972) and indirectly through its influence on sediment production and storage (Harmar and Clifford, 2006 and references therein). Tectonic deformation causes changes in channel slope, which in turn is responsible for variations in channel morphology, fluvial processes and hydrological characteristics of a river system (Jain and Sinha, 2005). As a signature of influence of tectonic activity this study utilizes earthquake (EQ) data to ascertain any changes in it and resulting effect on the fluvial systems of Gai and Simen rivers. Besides these natural forcing, floodplains are increasingly experiencing the pressure of accelerated population growth, exposing the rivers and floodplain to human intervention. Human intervention especially in the form of structural measures for flood protection, artificial levees, bridges and engineering structures are of common occurrence which have the potential to disturb the regular regime of the river and alter the riverine processes. The response of flow processes and channels morphology to engineering structures and regulation of alluvial streams have been studied widely (Surian, 1999 and references therein; Rinaldi, 2003; Surian and Rinaldi, 2003) and the studies not only demonstrate that process-response may generate remarkable channel changes, but also show that modes of change and response times vary considerably from one stream to another (Surian, 1999). Anthropogenic interventions in the form of potential flood course obstacles (culverts, dykes and roads crossing the floodplains), modifications accelerating runoff (river straightening) and obstacles for even distribution of sediments (embankments) in the floodplain (Langhammer, 2009) could critically affect flood morphogenesis and riverine process. Bank protection structures affect channel morphology and the river's flow dynamics. Bank protection increases the stress on the riverbed, which becomes more vulnerable to erosion than the protected riverbank (Yao et al., 2011). Flood embankment failures usually results in high-velocity flow across the floodplain and land degradation and/or structural damages (Gilvear and Black, 1999 and references therein).

4.2.1 Changes in rainfall regime

The trend analysis of total annual rainfall of the three stations Pasighat (upstream), Dhemaji (middle reaches) and Lakhimpur (downstream) show a continuous decline over the years. The trend analysis of the total rainfall during the monsoon season (Figure 5), which is the period of rainfall maxima in the region, also shows a declining trend indicating a negative feedback to discharge and water inputs in the catchment of the rivers. Therefore, an increase in the rates of deposition in both the rivers certainly could not be attributed to an increase in the generation of the same due to increase hydraulic pressure which may be caused due to increase rainfall in the catchments.

4.2.2 Effect of tectonics

Trend analysis (1950-2014) of Earthquakes (magnitude 3.0-8.6) within a 500 km radius of the region was carried out using data from Advanced National Seismic System (ANSS), USGS to establish the role of tectonic activity on river dynamics and process changes. Although it is difficult to ascertain a direct link of tectonic activity with the changes in overall river processes, but an increased number of seismic activity could be suggestive of probable influences. Trend analysis of earthquakes of different magnitude (Figure 6) shows there is an overall increase in the frequency of occurrence of small to medium range earthquake. In this regard it is important to appreciate the fact that this is a global trend which is generally attributed to enhanced capacity of detecting EQs. Great earthquake with a magnitude 8 and above which have the capability to bring about large surface modification and change the river regimes are completely absent during the period except the Great Assam Earthquake of 1950, which is the last great EQ in this region.

4.2.3 Anthropogenic role

Human activity in the form of engineering structures such as construction of dam, embankments, artificial straightening, diversion, and culverting have direct bearing on the fluvial systems and is recognized for long time (Gregory, 2006). A systematic listing of human interventions and engineering structures in the study region are presented in Table 4. Embankments, as part of flood protection measures, were constructed from 1950s to late 1980s in these two rivers. Though provided protection to crops and land from floods in the initial years, these embankments, of late has become ineffective and instead became a flood accentuating factor as evident from the frequent breaches. The roads and the railway bridge that intersect these two rivers act as an artificial levee. Together with embankments these structures have increased the vertical capacity of the river but restricted its horizontal span. As a result the river is not able to distribute its sediment evenly on the floodplain and deposits them on the bed. Because of deposition on the river bed, significant bed-aggradation has taken place in both the rivers which is noticed during field visits. Rapid bed-aggradation has reduced the carrying capacity of the river resulting in channel congestion. The river, unable to carry the extra load of sediments, overtops artificial levees during high stages of flow. This results in inundation and deposition of coarser sediment on the floodplains.

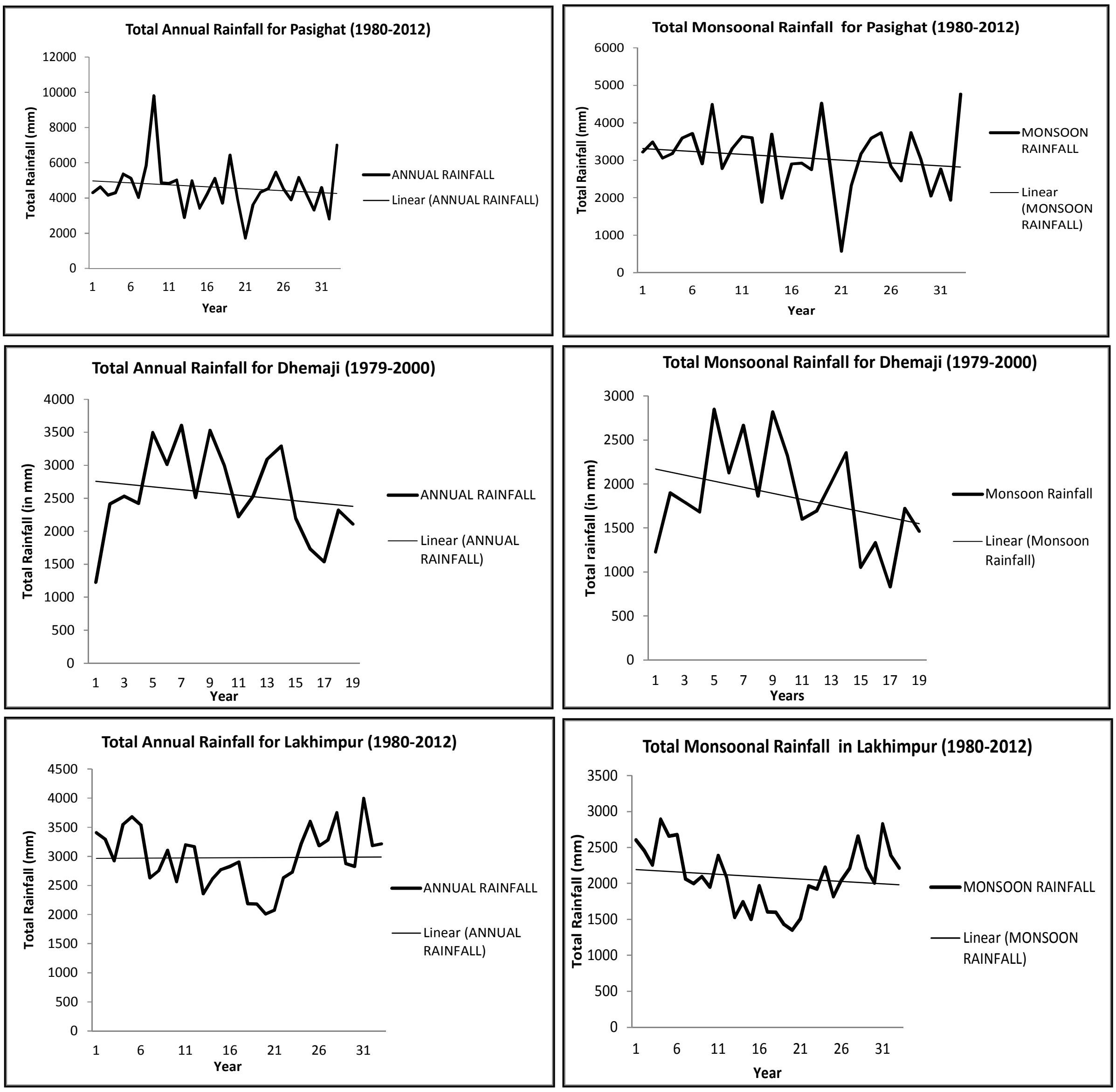

Figure 5: Rainfall pattern (annual and monsoonal total) in the study region for three different stations.

Table 4: Lengths of embankments and number of bridges over the two rivers

	Embankment		Bridges	
	Left Bank	Right Bank	Road Bridge	Railway Bridge
Gai river	17.79 km	41.198 km	21 (5 concrete)	1
Simen river	3.239 km	19.58 km	3 (2 concrete)	1

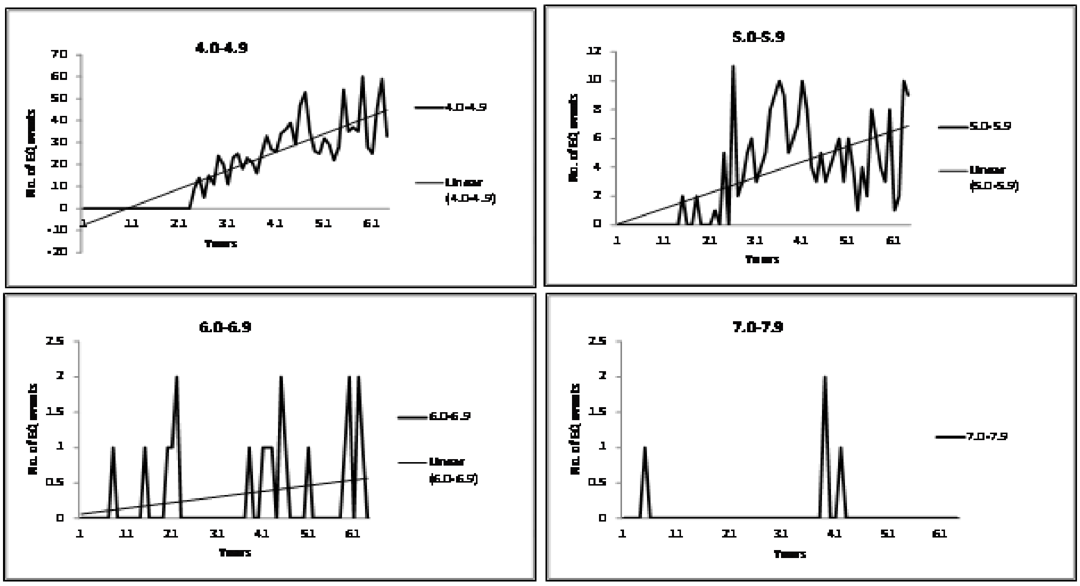

Figure 6: Temporal variability and trend analysis of earthquakes of different magnitudes in an around the study region from 1950-2013.

The effect of National Highway-52 that runs across Gai river is evident from the avulsive migration pattern. Gai river experienced 20 breaches during 1983-2012 of which 17 breaches are in the downstream of railway and road bridge (Statistics collected from Embankment and Drainage Department, Dhemaji, Govt. of Assam). To construct the railway and road bridge in its middle reaches the river is artificially straightened up to a length of approximately 7 km with the help of embankment and spurs (Figure 7). The river has become funnel shaped due to significant reductions in its width in this section, deforming its morphology and eventually altering its channel capacity. Frequent breaches in this section of the river have resulted in huge avulsive shifts in the river bankline and deposition of coarser sediments in the adjacent floodplains. The avulsive shifts and swinging migration pattern could be easily deciphered form Figure 8.

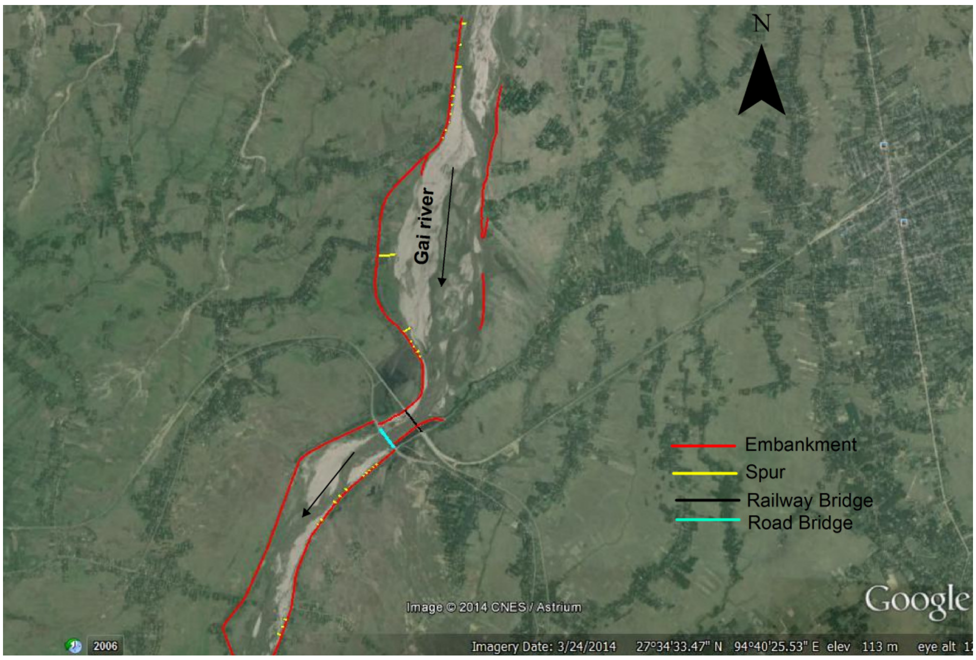

Figure 7: Artificial straightening of Gai river for construction of railway and road bridge in its middle section.

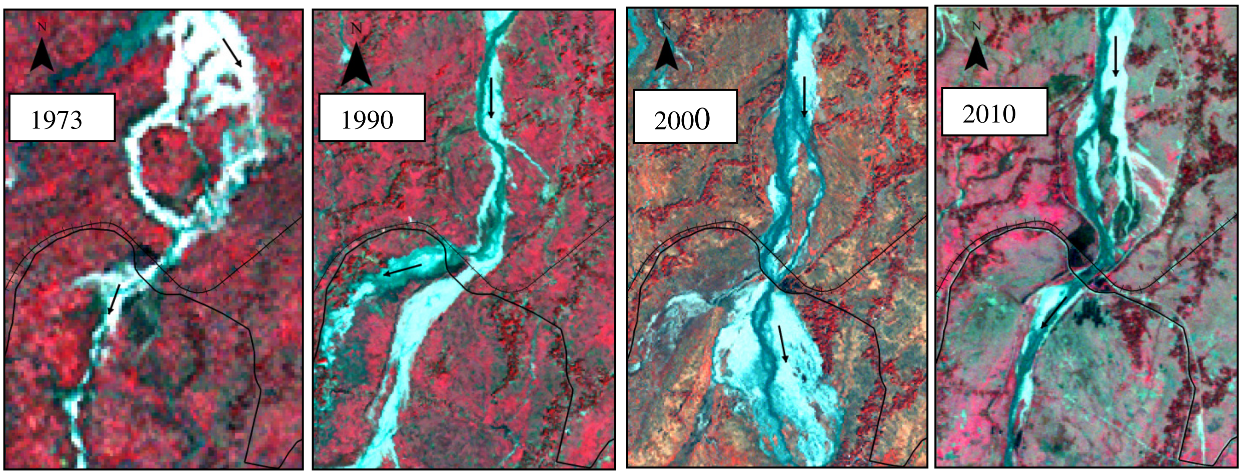

Figure 8: False colour composites of Landsat images showing avulsive river migration in Gai River downstream of the road and railway bridges in different periods.

Confluence migration in Simen river leading to river shortening emerged as the major process during the study period. Although the exact cause of such behaviour could not be determined, it is worthwhile to note that a study by Lahiri and Sinha (2012) attributed this unidirectional avulsive shifts to cross-valley tilting in the rivers of this region. The same probably is applicable to Simen river that showed a continuous eastward migration of its confluence. This process has resulted in significant acceleration in the rate of deposition in the floodplains of Simen river. The channel course that the river abandons is filled with sediments and while moving to a newer course the river gradually deposit its sediments throughout the floodplain on its way to the new course. The studied rivers present a unique case of different category of rivers that may be termed as "partially confined rivers". Such a terminology is justified in the sense that these rivers are modified and confined in places where there are objects of economic interest in the floodplains and are open and free flowing in other parts. At times one bank is embanked with artificial levee leaving the other unhindered. While there is no dearth of studies on river behaviours of freely meandering and confined rivers in the scientific repositories but behaviours of partially confined rivers are yet to be explored in depth. Therefore, these partially confined rivers present distinctive field of interest which needs notice of the geomorphologists'.

5. Conclusions

In this work process dynamics of two partially-confined rivers of Upper Brahmaputra valley is assessed which are undergoing accelerated geomorphological changes. The results show a reversal in process dominance in the form of rate of deposition surpassing rate of erosion in recent decades for both the rivers. River migration in the middle reaches of Gai river and confluence migration in the downstream of Simen river emerged as the dominant processes affecting other fluvial processes. Analysis of factors controlling these processes show a clear indication that anthropogenic intervention in the form of engineering structures and structural measures of flood control are playing a major role in process dynamics. Rainfall regime did not show any significant trend to attribute to an increased generation of surface runoff. Tectonic activity though influential, did not yield a clear-cut connection. The location of breaches, the points of avulsion and spatial distribution of deposition all indicates that the process dynamics in these two rivers are essentially controlled by anthropogenic interferences.

Acknowledgements

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