Spatio-Temporal Changes In The Fluvial Geomorphology In A Part Of The Upper Assam Area And Its Correlation To Subsurface Geology

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Abstract: The fluvial dynamics of two major tributaries of the Brahmaputra River, the Dikhow and the Dhansiri in a part of the upper reach of the Brahmaputra valley (Assam, India) adjacent to the Mikir hills and the Naga Patkai thrust belt has been studied over a period of ninety plus years (1915-2008) in the GIS environment by using topographic maps, satellite imageries, SRTM data, and seismotectonic information of the area. The temporal change in the morphological signature of the Dikhow River is least which is represented in the high correlation coefficient of its sinuosity values for different segments over the aforesaid period. The Dhansiri River on the contrary shows a very poor correlation coefficient for the same parameter. This is most probably due to the ongoing neo-tectonism about the Jorhat fault. The study makes an effort to locate areas of valley subsidence as well as upliftment. When compared with the available database of basement, it was observed that the Jorhat fault separates the study area distinctly into two tectonic blocks, one is the Dhansiri valley on the south-western part of the Jorhat fault, and the other is the subset of the upper reach of the Brahmaputra valley. A conceptualized 'pop-up' model is proposed, that relates the Himalayan frontal thrust (HFT) with the popping up Mikir Hills in the eastern front from one end and westward thrust front of the Naga thrust in the other end causing upliftment of south western part of the study area (Dhansiri valley) that explains clearly the avulsive tendency in the Dhansiri River and its drastic change in the geomorphological signature.

Keywords: Dikhow, Dhansiri, Jorhat fault, neo-tectonism, river dynamics, pop-up.

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1. INTRODUCTION

1.1 General

The forms of rivers or streams and the processes occurring in the fluvial geomorphology are described by a large number of parameters: channel width and depth, dissolved sediment load, suspended load, bed load, channel slope and sinuosity, flow velocity, channel roughness, and many others. An alluvial river is also known as a graded river, as alluvial rivers satisfy the state of dynamic equilibrium which is obviously the state of ultimate balance between driving forces and the resisting forces. Rivers tend to deflect by surface warping. When rivers encounter zones of active subsidence or uplift, their normal longitudinal profile get deformed. Deflection of the river around uplifts or into a zone of subsidence will manifest as an abrupt shift in the river course coincident with the deformed zone. Streams naturally tend to gravitate towards the subsided zone, if the zone is proximal to the river and there are no topographic barriers between the river and the zone. In turn, a river will tend to cross a zone of uplift if the rate of stream incision is substantially greater than the uplift rate. This is especially true if the river course is well established at the site of uplift before deformation begins [1]. In general, a river restores a steady grade by aggrading upstream and downstream of an uplift. Similarly, rivers will tend to incise in regions of steepened slope entering a subsided zone, and aggrade in the low-gradient reaches over the axis of subsidence.

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Loss of stream power and aggradation is an anticipated response for streams encountering lowered slopes on the approach to the axis of an impeding uplift. Because of the loss of load accompanying aggradation, and the increased slopes, such streams can be expected to have increased erosive power and degrade as they cross the uplift axis and proceed across the downstream flank. If streams fail to reclaim sufficient load by degradation of the uplift, however, they will not aggrade downstream of uplifts and will continue to erode. Similarly, areas of subsidence will not tend to experience aggradation if the streams are supply-limited upon entering the subsided zone [2]. It is to be noted that a meandering channel responds to increased slope by increasing its sinuosity or decrease its sinuosity as an adjustment to decreased slope under a particular threshold limit. In this study, the dynamics of two tributary rivers, the Dikhow and the Dhansiri belonging to the south bank of the upper Assam basin of the Brahmaputra valley have been monitored and quantified over a period of ninety years in the GIS environment after precise georeferencing of the old topographic maps and the recent satellite imagery. Subsequently, the nature of the river dynamics was superposed on a prominent structural element of the area called the 'Jorhat fault' and a conceptual model of the basin dynamics has been suggested to explain the fluvial dynamics observed.

1.2 The study area

The study area (Fig.1) lies within the upper Assam shelf, in the south bank of the Brahmaputra valley and is confined within 93.58^0 – 95.24^0 longitudes and 26.25^0 – 27.26^0 latitudes. The area is seismically active and locates a number of major earthquakes. The area has a number of large oil & gas fields.

1.3 Objectives

The objectives of the study are four fold:

1. Qualitative as well as quantitative understanding of the fluvial dynamics shown by the rivers, the Dikhow and the Dhansiri over a period ranging from 1915 - 2008.

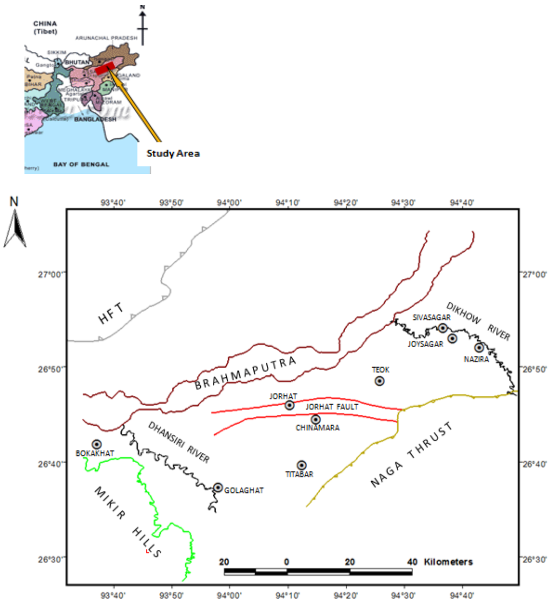

Figure1: *Location Map of the Study Area as a part of Assam Shelf.*

2. To locate the areas of valley subsidence and uplift for the strip lying within the Dikhow River and the Dhansiri River.
3. To understand the role played by the 'Jorhat fault'.
4. To conceptualize the ongoing basin dynamics in the Dhansiri valley area.

2. METHODOLOGY

For the present study, the IRS-P6-LISS-3 images acquired on in 2008 with a spatial resolution of 23.5 m and older topographic maps of 1:253,440 scale corresponding to 1912-1926 and 1977 (scale: 1:250,000) have been used. Digital image processing of the satellite images obtained from the National Remote Sensing Centre, Hyderabad, India, was carried out to enhance the geomorphic features for mapping. Shuttle Radar Topographic Mission (SRTM) data with spatial resolution of ~90m and vertical resolution of ~1m were used to find point elevations and for computing slope. All temporal data were georeferenced and registered on a common platform by using the software ERDAS Imagine 9.1. The data inventory (primary and secondary) for comparing different themes on the surface and the subsurface was developed in the Arcview GIS 3.2a system. As we all know that, rivers will tend to be deflected by surficial warping, which is mostly observed river deforming phenomenon as because when rivers encounter zones of active subsidence or uplift, their normal longitudinal profile will be deformed. Deflection of the river around an uplift or into a zone of subsidence will be manifested as an abrupt shift in the river course coincident with the deformed zone. Streams naturally tend to gravitate towards the subsided zone, if the zone is proximal to the river and there are no topographic barriers between the river and the zone. In turn, a river will tend to cross a zone of uplift if the rate of stream incision is substantially greater than the uplift rate. This is especially true if the river course is well established at the site of uplift before deformation begins [3].

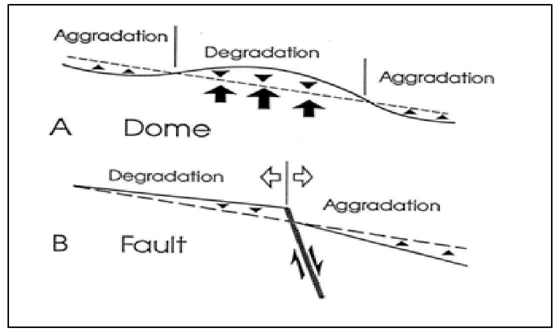

Figure 2*(a): Generalized aggradation and degradation response of a stream as it crosses a dome (A) and a fault (B). (source: [1])*

Fig.2(a) depicts generalized aggradation and degradation response of a stream as it crosses a dome and a fault. In general, a river restores a steady grade by aggrading upstream and downstream of an uplift. Similarly, rivers will tend to incise in regions of steepened slope entering a subsided zone, and aggrade in the low-gradient reaches over the axis of subsidence. Loss of stream power and aggradation is an anticipated response for streams encountering lowered slopes on the approach to the axis of an impeding uplift. Because of the loss of load accompanying aggradation, and the increased slopes, such streams can be expected to have increased erosive power and degrade as they cross the uplift axis and proceed across the downstream flank. If streams fail to reclaim sufficient load by degradation of the uplift, however, they will not aggrade downstream of uplifts and will continue to erode. Similarly, areas of subsidence will not tend to experience aggradation if the streams are supply-limited upon entering the subsided zone [4]. In this study of fluvial geomorphology, sinuosity plays a major role while calculating river dynamics. Sinuosity can be defined from Fig.2 (b) as;

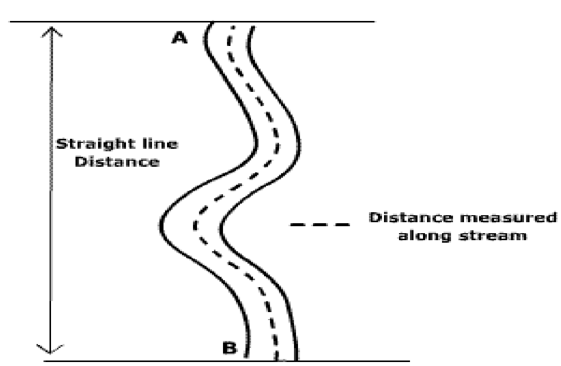

Figure 2(b): *Definition and Calculation of the Sinuosity of a River Channel. (source: [1])*

$$\text{Sinuosity ratio} = \frac{\text{Distance measured between two points along stream}}{\text{Straight line distance between two points}}$$

3. DATA INTERPRETATION

In Fig. 3(a) & (b), the segmentations of the rivers are done in a way to divide the rivers into a number of stretches. The total valley length for a particular river is the straight distance

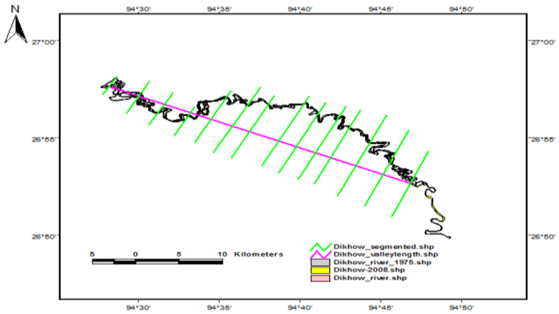

Figure 3(a): *Segmentation of the Dikhow river and the associated valley length at three different ages i.e. in 1915, 1975 and in 2008.*

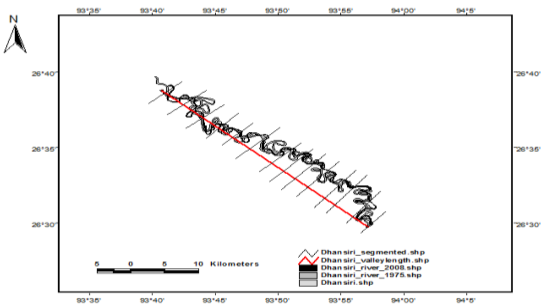

Figure 3(b): *Segmentation of the Dhansiri river and the associated valley length at three different ages i.e., in 1915, 1975 and in 2008.*

between the first point considered for the present study in the extreme upstream side to the confluence point (locally called mukh, Dikhowmukh, Dhansirimukh etc.) in the downstream side where they join the Brahmaputra. Here, although the channel length of a river at a particular stretch in different times is found to be different, the corresponding valley lengths are kept fixed. Then across the stretches of the two rivers, the river parameters as well as the associated elements were studied. In the Fig.4(a), zones 1,2,4,5 are the subsided blocks, whereas zone 3 is a region of upliftment in Dhansiri River, which establishes the fact that, with the increase in slope value the corresponding sinuosity increases, whereas with decrease in slope or at the zones of upliftment the sinuosity of a river decreases.

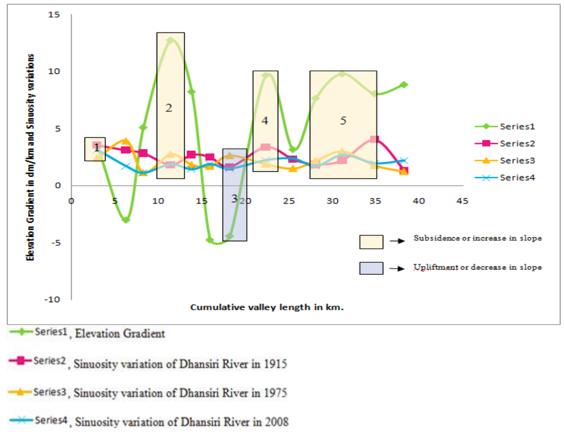

Figure 4(a): *Identification of some prominent anomalous zones in case of the Dhansiri River.*

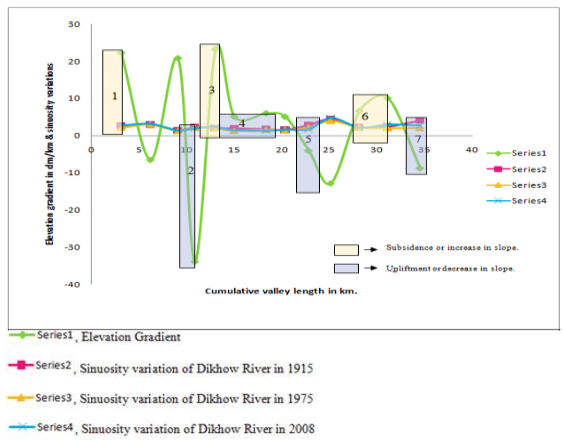

Figure 4(b): *Identification of some prominent anomalous zones in case of the Dikhow River.*

From the Fig.4(b), it has been observed that zones 1, 3, & 6 are due to subsidence or increase in slope amount, whereas zones 2,4, 5 & 7 are due to upliftment or decrease in slope. From the observation of fluvial dynamics in case of the Dikhow and the Dhansiri River, we may locate the region of upliftment as well as subsidence in the study area. It is seen that, in case of the Dhansiri River, the total sinuosity values are 2.60 (in 1915), 2.15 (in 1975), & 2.02 (in 2008). Thus a sort of overall decreasing tendency is noticed in sinuosity of the Dhansiri River, which yields the fact that the whole valley area adjacent to the Dhansiri River is uplifted. Also, a small part of the Dhansiri valley area is subsided (Mariani area) adjacent to the Naga thrust here the Dhansiri River response is not prominently observed. On the other hand, in case of the Dikhow River, the total sinuosity value in three different times i.e. in 1915, 1975 & 2008 decreases in an area confined between longitude 94.47ºE and latitude 27ºN to 94.57ºE and 26.95ºN where total sinuosity values of the Dikhow River are 1.28 (in 1915), 1 (in 1975), & 1.16 (in 2008), which is obviously uplifted; although here it is to be mentioned that the Dikhow River seems to have stabilized itself lately. The valley area adjacent to the Dikhow River, which is bounded by the Naga thrust on its south, confined between 94.60ºE and

26.94ºN to 94.78ºE and 26.86ºN is prominently subsided as observed from the sinuosity values of the Dikhow River, which are 1.19 (in 1915), 1.13 (in 1975), & 1.20 (in 2008,) which shows a marginal overall increase in sinuosity value. But it is to be noted from the overall sinuosity variation of the Dikhow River that, the subsidence might be recent phenomenon.

The above discussion is also substantiated by the Basement configuration (Fig.6) studied from the integration of seismic data and well informations.

When a reach of a stream is steepened with respect to the adjoining reaches, it defines a topographic knickpoint. Such a steepened reach could develop in the absence of tectonism (or eustatic change) simply due to a difference in the erodability of the bedrock: more resistant rocks will tend to underlie steeper reaches of a stream. Tectonically generated knickpoints can be formed through differential folding or faulting of a reach of a river [2].

It is clearly visible from the Fig. 5(a) and 5(b) that, the steepnesses of the knickpoints in case of the Dikhow River are greater in magnitudes than those in case of the Dhansiri River. This important observation yields the fact that, the subsurface of the region nearby the Dikhow river might have a no. of folds and faults as well as thrusting like structures of greater magnitudes than the regional subsurface nearby the Dhansiri River.

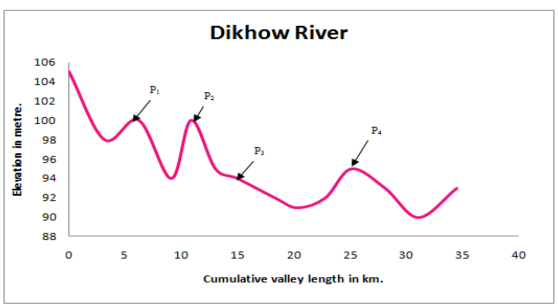

Figure 5(a): *Development of four fluvial knickpoints p_1, p_2, p_3, p_4 of the Dikhow River.*

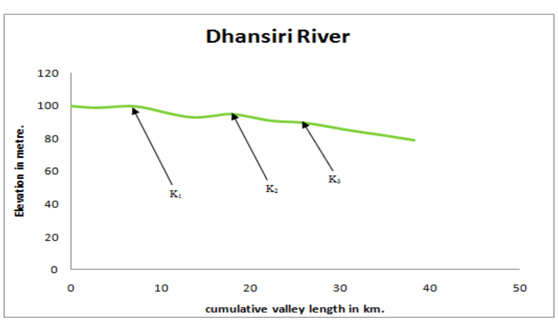

Figure 5(b): *Development of three fluvial knickpoints k_1, k_2, k_3 of the Dhansiri River.*

Correlation coefficient is defined as a measure of the interdependence of two random variables that ranges in value from -1 to +1, indicating perfect negative correlation at -1, absence of correlation at zero, and perfect positive correlation at +1. Now, while determining the correlation coefficients of the two rivers, the Dikhow and the Dhansiri over the ninety years duration, we have found the following values in terms of their sinuosity variations:

In case of the Dikhow River:
Correlation coefficient comparison Dikhow 1915 & Dikhow 1975 = 0.80768
Dikhow 1975 & Dikhow 2008 = 0.89256
Dikhow1915 & Dikhow2008 = 0.81379

In case of the Dhansiri River:
Correlation coefficient comparison Dhansiri 1915 & Dhansiri 1975 = 0.03025
Dhansiri 1975 & Dhansiri 2008 = 0.13173
Dhansiri 1915 & Dhansiri 2008 = 0.18763

Thus, we may conclude that, the relative shifting tendency of the Dikhow River is very less over the period of ninety years, whereas the Dhansiri River shows prominent relative shifting during this course of time. In case of the Dhansiri River, it can be observed from the available datasets (topographic maps, satellite imagery) that, a sort of north-eastern avulsive tendency has been going on.

4. DISCUSSION

4.1 Jorhat fault and associated landmass nearby the Dikhow River and the Dhansiri River:

The basement contour map of the study area as shown in Fig.6 indicates that, there is a large no. of minor faults and Jorhat major fault act as primary tectonic agency, which have been influencing the river dynamics within the study area. It is evident from the basement contour map that, towards the north-eastern part of the Jorhat fault zone, the basement thickness increases; whereas towards the south-western parts of the Jorhat fault the basement thickness goes on decreasing and ultimately the Precambrian basement outcrops in the form of the Mikir Hills . Since the sediment thickness is very thin in the Northern part of the Mikir Hills, the activation of the Jorhat fault can only result into avulsion of the Dhansiri River towards the downthrown side because the

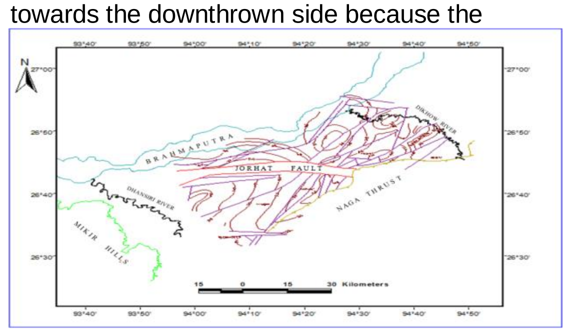

Figure 6: *Basement contour map of the study area (Basement thickness in km.) (Source: [5])*

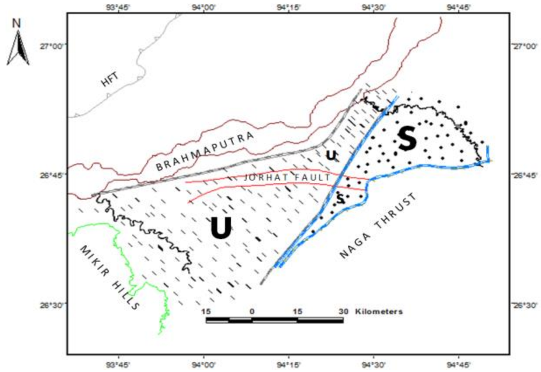

Figure 7: *Map showing tentative uplifted and subsided region in the study area. In the figure, U stands for uplifted block, and S stands for subsided block.*

possibility of incision is very less. On the contrary, as the basement thickness near the Dikhow River is large enough to be incised further, thus no prominent changes in the channel pattern of the Dikhow River have been observed. It is also remarkable from Fig. 4(a) & 4(b) that the landmass near the Dikhow River belongs mostly to the under-thrusted zones, whereas the landmass near to the Dhansiri River is having some prominent uplifted zones. Thus from the basement contour map, and the corresponding river responses, we may definitely arrive at the result that tectonics in this part of Assam Shelf provides very notable subsurface structural features.

4.2 Study of ongoing basin dynamics in the Dhansiri valley area:

A 'pop-up' mechanism for Mikir Hills [Fig.8(b)] can also be visualized in light of the model [Fig.8(a)] proposed by Bilham and England,2001[6] for the Shillong massif. Accordingly, the Jorhat Fault might be playing the role similar to the Oldham Fault, and Kopili lineament located in the southern margin of the Mikir Hills is comparable to that of the Dauki fault. The mechanical cause of deformation of Mikir Hills is the superposition of elastic stress caused by bending of the Indian plate and in-plane compressional stress from India's collision with Tibet. Whether the genesis of Mikir Hills is independent or a part of the overall genesis of the Shillong massif is yet to be established. Also, detail information about the sediment budgeting in the southern part of Mikir hills is not known very precisely. As a result, it is difficult to assert firmly the validity of the pop-up mechanism.

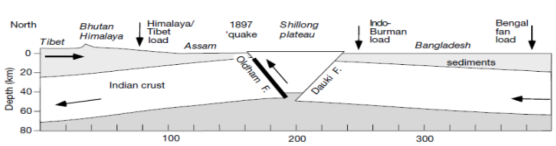

Figure 8(a): *North-South section from Tibet to the Bay of Bangle showing schematic geometry of 'Pop-up' structure of Shillong Plateau.(Source: [6])*

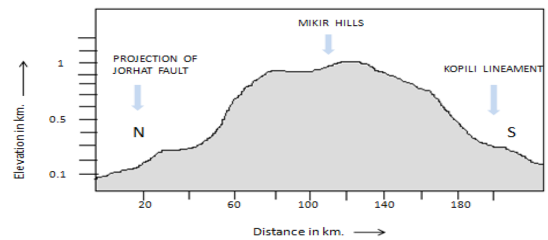

Figure 8(b): *Proposed topographic section through the central Mikir Hills, showing projected location of the Jorhat fault and the Kopili Lineament.*

The upliftment of the Dhansiri valley adjacent to the Mikir Hills can also be explained by 'Shifted leading edge' phenomenon as shown in Fig.9. The essential proposition is the juxtaposition of the Himalayan frontal thrust with the Mikir Hills, and formation of a new leading edge which might have been proceeding towards the Naga thrust. On the other hand, the western part of the Naga thrust is also showing a kind of overthrusting nature on the Dhansiri valley area. As a consequence, the intermediate region between the over-thrusting Mikir

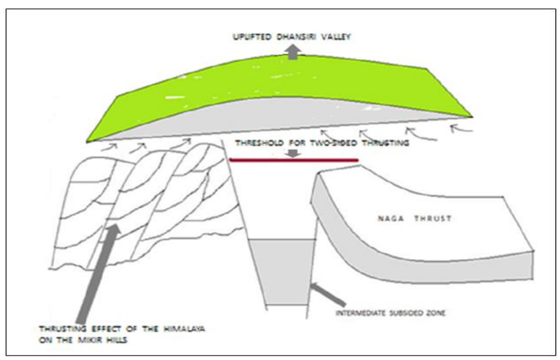

Figure 9: *A model for the ongoing basin dynamics in the Dhansiri valley area, where juxtaposition of the Himalayan frontal thrust (HFT) with the Mikir Hills and the shifted leading edge in the eastern front from one end and westward thrust front of the Naga thrust is causing subsidence in the intervening space as well as beyond a threshold in the Northern direction, is showing a remarkable upliftment, causing an avulsive tendency in the Dhansiri River and drastic change in the geomorphological signature over a period of ninety years.*

Hills and the Western part of Naga thrust seems to be subsided due to gradual upliftment on the both sides of the subsided block; whereas a threshold might have been reached beyond which the whole valley area is showing a major uplift causing an avulsive tendency in the Dhansiri River and drastic change in the geomorphological signature over a period of ninety years compared to the Dikhow River over the same time period.

4. CONCLUSION:

From the spatio-temporal study of the river dynamism over a period of ninety plus years from 1915-2008 for the Dhansiri and the Dikhow River, and a comparison of the basement topography along with the Jorhat fault, we may conclude that,

1) The dynamics of the two rivers, the Dikhow and the Dhansiri shows some significant changes over a period of ninety years (1915-2008) which is probably guided by the regional tectonic forcing. From the calculations of river dynamism, it is observed that the sinuosity values of the Dhansiri River are 2.60 (in 1915), 2.15 (in 1975) & 2.02 (in 2008), which indicate an overall decreasing tendency of sinuosity. Moreover, as the sediment thickness near the Dhansiri River is very less as manifested in the basement contour map, the Dhansiri River can't incise further its valley area; hence it shows an avulsive tendency in the north-east direction. On the other hand, the Dikhow River shows two distinct trends- the reach nearer to the Naga thrust area shows a sinuosity variation from, 1.19 (in 1915) to 1.13 (in 1975) and then 1.20 (in 2008), which probably shows subsidence. Whereas the distal part of the Dikhow River shows a sinuosity variation from 1.28 (in 1915) to1 (in 1975) and then 1.16 (in 2008), which is probably due to upliftment.

2) A strip encompassing the northern frontier of the Mikir Hills and its tapering continuation across the Jorhat fault towards the NNE direction seems to have uplifted. To be more specific the area ranges from longitudes of 93.68º to 94.56º and latitudes of 26.41º to 27.03º (Fig.7). Another smaller, almost triangular strip continuing along the Naga thrust and the intervening space between the eastern margin of the Mikir Hills seems to have subsided, which ranges from longitudes of 94.21º to 94.83º and latitudes of 26.46º to 26.99º (Fig.7).

3) The Jorhat Fault seems to play a major role in dividing the study area of Upper Assam shelf into two blocks, one is the Dhansiri valley on the south-western part of the Jorhat fault, and the other is the subset of the upper reach of the Brahmaputra valley. From the basement contour map, it is quite clear that the sediment thickness in the Dhansiri Valley area is very less, whereas the sediment thickness the north-eastern part of the Jorhat fault zone is much higher. The temporal change in the morphological signature of the Dikhow River is least which is represented in the high correlation coefficient of its sinuosity values for different segments over a period of ninety years (1915-2008). The Dhansiri River on the contrary shows a very poor correlation coefficient for the same parameter. This is most probably due to the ongoing neotectonism about the Jorhat fault.

4) The ongoing basin dynamics in the Dhansiri valley area might have an analogy with the proposed 'Pop-up' mechanism for the Shillong plateau where perhaps Jorhat fault is acting in a similar manner to that of the Oldham fault and the Kopili Lineament to that of the Dauki fault. However, the overall nature of uplift and subsidence might be fitted with the 'Shifted leading edge' due to the juxtaposition of the Himalayan frontal thrust (HFT) with the Mikir Hills in the eastern front from one end and westward thrust front of the Naga thrust in the other end, causing subsidence in the intervening space as well as beyond a threshold in the Northern direction, a remarkable upliftment is observed. This is substantiated by an avulsive tendency in the Dhansiri River and drastic change in the geomorphological signature of the Dhansiri valley area over a period of ninety years. However, a multi-disciplinary database is needed to be developed to validate the hypothesis on stronger footing.

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