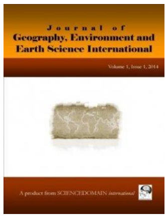

Journal of Geography, Environment and Earth Science International

13(1): 1-11, 2017; Article no.JGEESI.38082
ISSN: 2454-7352

Morphotectonic and Basin Parameters of the Noa-Dihing River, Eastern Himalayas

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Authors' contributions

This work was carried out in collaboration between both authors. Authors DK and BPD defined the problem and managed the interpretation part. Author DK performed the processing and data analysis and wrote the first draft of the manuscript. Author BPD did the refinement of the manuscript. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JGEESI/2017/38082
Editor(s):
(1) Anthony R. Lupo, Professor, Department of Soil, Environmental, and Atmospheric Science, University of Missouri, Columbia, USA.
Reviewers:
(1) José Martínez Reyes, University of the Ciénega of Michoacán State, México.
(2) Nisarg H. Bhatt, Institute of Seismological Research, India.
(3) S. B. Ota, India.
Complete Peer review History: http://www.sciencedomain.org/review-history/22347

Original Research Article

Received 10th November 2017
Accepted 13th December 2017
Published 18th December 2017

ABSTRACT

The Noa-Dihing River, an important tributary of the Brahmaputra River flows through two tectonic domains viz. Mishimi Massif and Naga-Patkai Range in the Eastern Himalayas. Active tectonics and tectonic evolution of a terrain are reflected in the basin geometry of a river. So it is easy to trace back the history of the involved tectonic forces involved the basin evolution through space and time by studying the river morphometric and the basin parameters. Seismological study of the basin and its surroundings is also another advantageous tool that helps better understanding of the evolution process, if corroborated with the morphometric and basin parameter data. The present results show existence of two distinct tectonic regimes that control the evolution of the Noa-Dihing river basin, the right bank part of the Noa-Dihing falling on the Mishimi Massif, and the left bank part and the upper catchment falling in the Naga-Patkai range of the Indo-Myanmar tectonic belt. From the results it appears that lithology is also one of the controlling factors for the arising basin geometry. The downstream part of the basin is structurally controlled and got tilted northward.

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Keywords: Morphometry; active tectonics; Mishimi Massif; Noa-Dihing.

1. INTRODUCTION

Noa-Dihing is one of the major eastern most left bank tributaries of the Brahmaputra River with its upper catchment covering the Naga-Patkai Hills and the hills of Mishimi Massif of south-eastern part of Arunachal Pradesh and its lower catchment covers Tinsukia and Dibrugarh districts of Assam, India (Fig. 1). It meets the Brahmaputra River near Dhola in the alluvial plains of the Brahmaputra. The Naga-Patkai Hills range represents the northeastern extension of the Indo-Myanmar Mobile belt and the Mishimi Massif represents the eastern syntaxial band of the Himalayas. The Noa-Dihing River is a 7^{th} order as derived from 90 meter spatial resolution of SRTM DEM following Strahler [1] and covers an area of 3006 sq. km. The geometry of the Noa-Dihing River in its evolutionary history keeps evidences of tectonic processes involved in this part the Himalayas as well as in the Naga-Patkai Hills range.

The river system's geometry has responded to the changes in the landform and adjusted to the tectonic changes. In general, the changes that take place in the landform may be depositional, erosional, tectonic or climatic, and sometimes in combination of any of the two or more. The morphometric analyses [1-6] have been used as proxies to examine the involvement of tectonic processes to the present landform changes [7, 8]. The morphotectonic parameters used in this study are - i) relief and slope, ii) drainage pattern, iii) longitudinal profile, iv) valley profile, v) hypsometry and vi) valley asymmetry factor [1-3]. All the parameters have been calculated/extracted using Rivertools 3.0 [9] software and 3 arc second SRTM (Shuttle Radar Topographic Mission) data with 90 meter spatial resolution.

2. DATABASE AND METHODOLOGY

The 3 arc second SRTM, Landsat 7 ETM+, Landsat 8 OLI and TIRS data, published maps along with the Survey of India topo sheets (on 1: 50000 scale) are used in the present study. The void contained in the SRTM DEM due to the presence of water body and steep slopes were filled by “SRTM FILL” software (http://3dnature.com/srtmfill.html).

Morphotectonic parameters have been derived using 3arc second SRTM DEM data and River Tool 3.0 software [9]. The valley profiles and relief map were generated from the SRTM DEM. The study is supported by relevant secondary data on geology and seismotectonics of the region. Geomorphological, geological, structural and litho-tectonics studies have been carried out through interpretation of, Landsat-7 ETM+ digital data and published geological [10] map, Seismotectonic Atlas of India and its Environs [11] and other published literature.

3. GEOLOGICAL AND LITHOTECTONIC SETTINGS

In the upstream part, the left bank catchment of the Noa-Dihing River is on the Naga-Patkai Range whereas the right bank catchment covers the hills of the Mishimi Massif. The lithotectonic units that cover the Noa-Dihing River basin are [11] (Fig. 1) - 1) Belt of Schuppen, 2) Accretionary Complex, 3) Accretionary Prism, 4) Older folded cover sequences overprinted by Himalayan fold-thrust movement and 5) Older cover sequences affected by Himalayan fold-thrust movement. Lithologicaly the Mishimi Massif part of the Noa -Dihing Basin and its surrounding area comprise of from SW to NE [12] (Fig. 2) are Se-La Group, Miri Formation, Tidding Serpentinite, Tidding Formation and Lohit Migmatitic Complex. Se La group is the suite of high grade to medium grade rocks named after the Se La pass in West Kameng District [12,13]. It mainly comprises of garnetiferous gneiss, sillimanite-kyanite-garnet bearing gneiss, migmatite, lit-par-lit biotite gneiss, calc gneiss/ marble, staurolite bearing schist, tourmaline granite, quartzite and pegmatites. Lithology and grade of metamorphism divides the Se La Group in two formations: 1) Taliha Formation and the Galensiniak Formation [12]. Miri Formation belongs to the Lower Gondwana Group and comprises of quartzite with interbedded grits and carries few thin bands of pink slaty shales [12, 14]. The Tidding Formation is resting in between the Yang Sang Chu Formation and Hunli Formation in the Dibang Valley. The Tidding Formation comprises of Tuting meta-volcanics altered to chlorite phyllite or chlorite-actinolite phyllite, thin bands of crystalline limestone and carbonaceous phyllite. Besides these, dykes and sills of ultramafic and amphibolite, minor intrusions of granodiorite and lenticular bands of magnesite associated with ultramafics [12] are also reported. The ultramafics show alteration to serpentinite which are well exposed at Tidding and also mapped near Myodia pass, Mayi hills [15], north of Tuting and Rayalli [12]. The Granitoid Complex extends from Namcha Baruwa in the northwest to Dapha Bum in southeast abutting against Naga-Patkai range along Mishimi Thrust. The Granitoid Complex comprises of diorite, granodiorite, tonalite, hornblende-biotite granite and leucogranite.

The lithological units that cover the Noa-Dihing River and its surroundings in the Naga Patkai range [12] (Fig. 2) are the Dihing Group, Tipam Group, Barail Group and Disang Group in descending stratigraphic order. Here the Tipam Sandstone Formation of the Tipam Group overlies the Barail Group unconformably and conformably overlain by the Girujan Formation of the Tipan Group. Tipam Sandstone Formation is mainly consists of arenaceous sediments

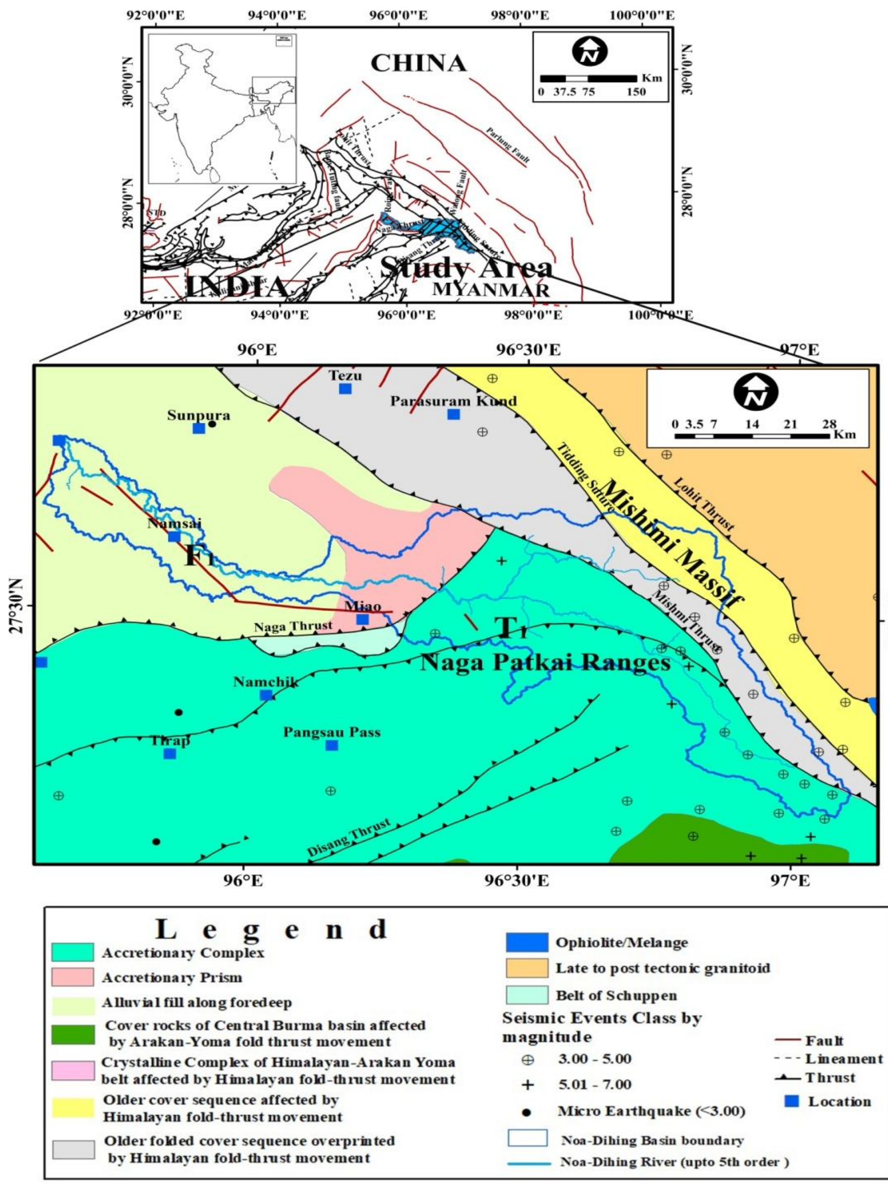

Fig. 1. Litho tectonic map of the Noa-Dihing River basin. This map is adopted from Seismotectonic Atlas of India [11] modified and updated through Landsat- 7 ETM+ satellite image interpretation and earthquake data from USGS, http://earthquake.usgs.gov/search/; ISC, http://www.isc.ac.uk/ iscbulletin/ search/catalogue/; and NEIST (2012) [16]

comprising grits, lenses of conglomerate, sandstone and minor shale and possesses minor lenses of coal, and oil and gas. Presence of epidote in the Tipam Sandstone may infer upliftment of the Lohit Himalayas during its deposition [12]. The Dihing Formation is the uppermost Tertiary sequence which comprises of boulder to pebble-sized clasts of quartzite and gneiss embedded in a matrix of sand and clay, carbonized wood and small lenses of lignite. Rocks of Barail Group occur in two different depositional environments [12] – 1) The one occurring to the south of the Disang Thrust belongs to the geosynclinal facies and 2) the other, north of the Disang Thrust and belongs to shelf or platform facies and is coal-bearing. Evans and Mathur (1964) [17] divided the Barail Group in the Naga-Patkai Range in three formations, namely, Nagaon, Bargolai and Tikak Parbat formations. The Disang Group is unfossiliferous dark grey compact shales with frequent intercalations of hard massive grey and reddish sandstone.

The main tectonic elements that present in this area are thrusts of 'Belt of Schuppen' including Naga Thrust to the north, Disang Thrust to the south and other significant thrusts in between. The Naga Thrust and T1 thrust abuts against the Mishimi Thrust in the east (Fig. 1). The Mishimi Thrust and Tiding Suture strike NW-SE direction and are almost parallel to each other.

4. RESULTS

The 3 arc second data has 90 meter ground resolutions and as such the minimum length of a first order stream derived is 90 meter. Upon generating the stream model it is found that the 7th order Noa-Dihing River has 48 numbers of 4th order basins, 9 numbers of 5th order basins and 2 numbers of 6th order basins. The sub-basin parameters for 4th and above orders basins are considered for this study. The sub-basins below 4thorder basins are not considered since they may miss-match lithological and structural variations in the small basins.

4.1 Relief

Relief mapping sheds light on the landform processes of the Noa-Dihing River basin (Fig. 3), noticeably that the right bank of the basin which fall in the Mishimi Massif covering the north, north-eastern, eastern and south eastern parts of the basin has higher relief compared to the left bank. The left bank of the Noa-Dihing river basin

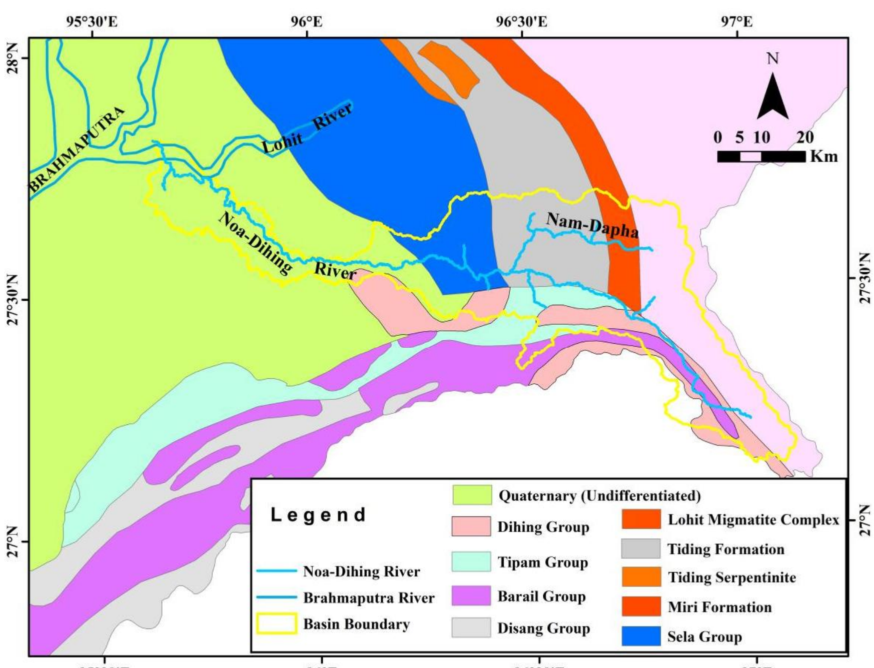

Fig. 2. Geology map of the Noa-Dihing River Basin and its surrounding area adopted from GSI (1998) [10]

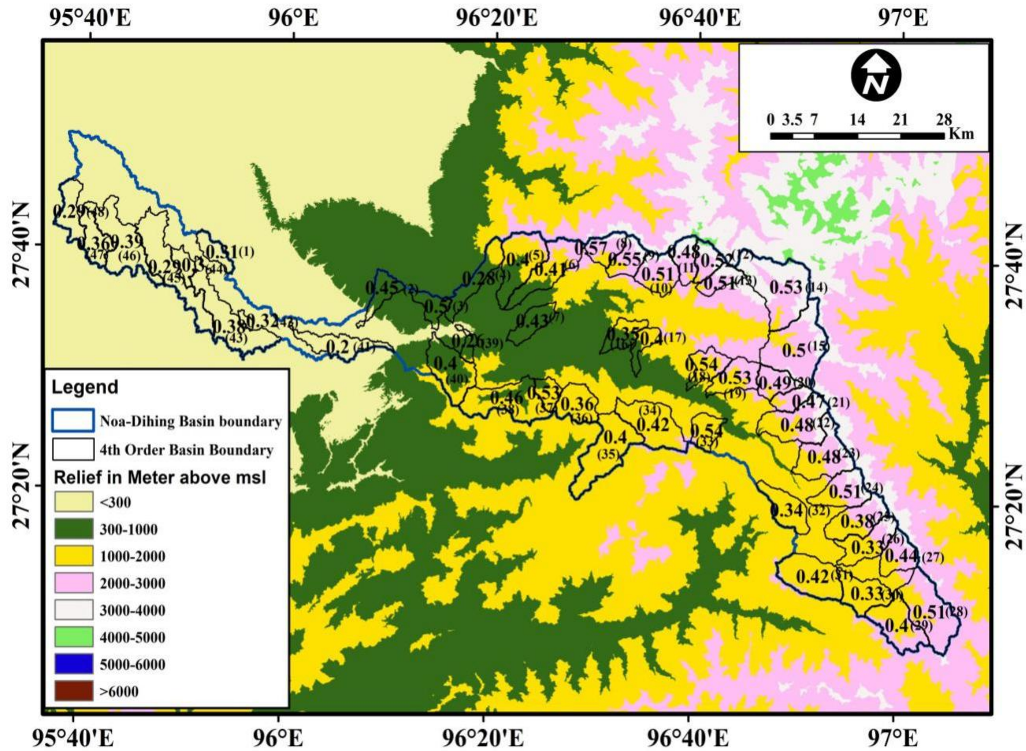

Fig. 3. Relief and sub-basin map of the Noa-Dihing River Basin. The relief map is prepared from 3 arc second SRTM DEM. The hypsometric integral (HI) values of the 4th, 5th and 6th order sub-basins are indicated within the sub-basins. The HI values for the 4th are indicated along with the basin numbers in parenthesis

mainly falls in the Naga-Patkai Range that comprises of accretionary complex whereas the right bank is comprises of 'older cover sequences' and 'older folded cover sequences'. The downstream part of the river basin possesses lower relief. The foothills region comprises of accretionary prism.

4.2 Drainage Pattern

The Noa-Dihing River and its tributaries pass through number of thrust zones which likely to control the channel development and patterns. It follows the regional structural trend of the region. The drainage map (Fig. 4) infers that the rectangular drainage pattern dominates in the middle reach while the upstream reach shows dendritic pattern with rectangular component at few places. The dendritic pattern is also dominant in the downstream reach of the basin. The channels in this basin follow the major lineaments present. In the upstream part it flows along T_1 thrust and in the downstream part it flows along the F_1 Fault [11].

4.3 Longitudinal Profile

Two longitudinal channel profiles LP1 (containing 7th, 6th and 5th order courses) of Noa-Dihing River and LP2 (containing 6th and 5th order courses) of Nam-Dapha River have been plotted (Fig. 5). In the longitudinal profile LP1, four knick points have been observed and measured. The knick points occur where the profile cut across by Tidding Suture, Mishimi Thrust, Naga Thrust and F_1 fault respectively. In the longitudinal profile LP2, two knick points are observed, viz., KP5 and KP6 in the locations transverse by the thrust T_1 and Naga Thrust. The data of the knick points are presented in Table 1.

4.4 Valley Profile

Nine valley profiles (marked as VP1, VP2,........ VP9) across the Noa-Dihing River from right bank to left bank have been drawn where there is no confluences of its tributaries to the main trunk channel (Fig. 4 and 6). The valley profiles VP1, VP2, VP3, VP4, VP5, VP6, VP7 and VP8 show steeper right bank and gentle left bank. While the other valley profiles (VP7 and VP9) show steeper left bank and gentle right bank which are formed due to the influence of T1 thrust and Naga Thrust.

4.5 Hypsometry

Among the two 6th orders sub-basins, the sub-basins covering the Mishimi Massif part possesses comparatively higher HI value (HI 0.46) than the sub-basins covering the south-eastern part of Arunachal Pradesh (HI 0.36). The 5th order sub-basins infer that the sub-basins of the middle reach namely the basins B, C, E, G and H have higher HI values and possess S-shaped hypsometric curves (Fig. 8). The higher HI values and convex upward hypsometric curves indicate that the middle reach of the Noa-Dihing River possesses geomorphologically younger topography. For better understanding of the tectonic activity the 4th order sub-basins of the Noa-Dihing have also been investigated (Fig. 3). The 5th order sub-basin F is falling in the area covered by boulder bed and sand dominated Dihing Formation and sandstone dominated Barail Group of Tertiary sequence which is highly susceptible to erosion and is having low HI values (0.32). The middle reach of the Noa-Dihing is occupied by the Schuppen Belt and lithologically covered by the Barail Group and Tipam Formation dominated by sandstones along with Dihing Formation dominated by boulder beds and sands at few places. So, higher HI values in this part appear to be tectonically active.

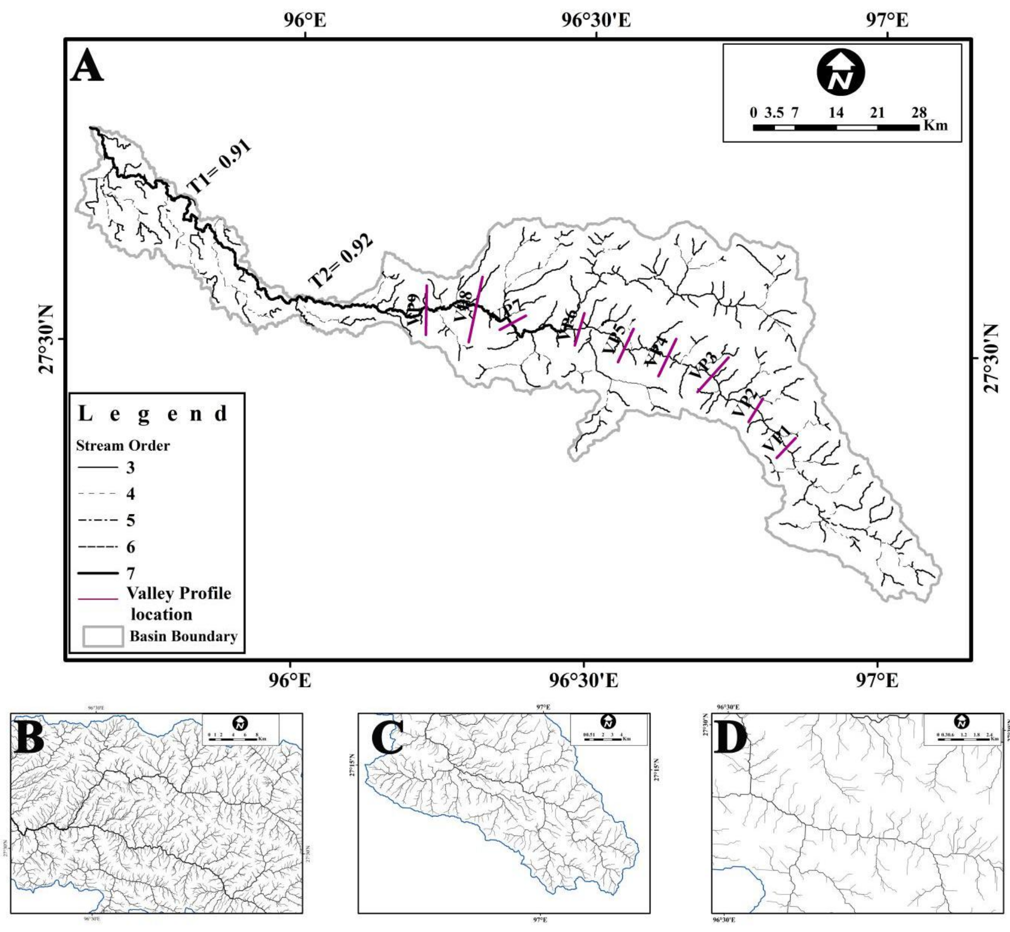

Fig. 4. A) Drainage map of the Noa-Dihing River basin along with valley profile sections. The red line (dotted) indicates the position where transverse topographic symmetry has been marked. Evidences of rectangular (B), dendritic (C) and trellis (D) patterns in Noa- Dihing drainage system

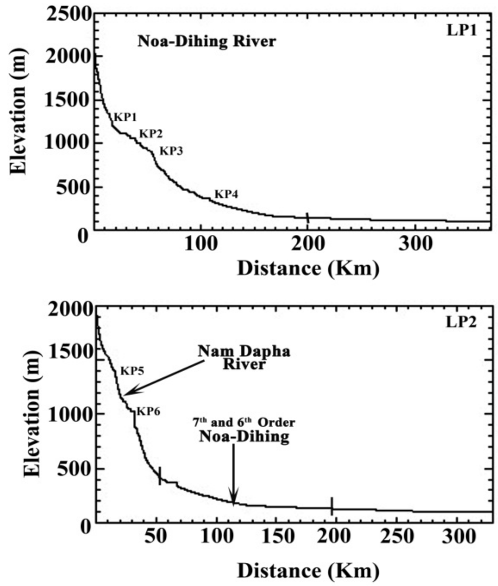

Fig. 5. Longitudinal profiles of Noa-Dihing River (LP1), and Nam Dapha extending it through its confluence to Noa-Dihing (LP2)

4.6 Basin Asymmetry Factor

The area on the right side of the drainage divide (A_R) has been calculated to be 1814 sq km against the total area (A_T) of the basin is 3006 sq km. Hence, the asymmetry factor has been calculated to be A.F= 60.33 indicating a moderately asymmetrical basin.

The Basin map of the Noa-Dihing River shows that the river channel touches the basin boundary of the right bank at the downstream area where the river pattern changes from a straight to a meandering channel. The basin on the right side of the drainage divide can be separated into two parts and the valley asymmetry factor has been calculated accordingly for each of the parts [18]. For the upstream part, asymmetry factor, $A.F_1$=57.21(A_R = 1814 km^2 and A_T = 3007 km^2). It indicates that the basin is tilting towards south and south-west. While, for the downstream part, asymmetry factor, $A.F_2$=3.13 (A_R = 94 km^2 and A_T= 1720 km^2). It indicates that the basin is tilting towards north and north-east.

Shape of the basin is also influenced by the tectonic activities of the structures present in that region. The eastern side the basin is elongated and the river turned towards the NW direction due to the influence of the T_1 Thrust, Mishmi Thrust and Tidding Suture. The river shifted towards North in the middle reach, due to the influence of the Naga Thrust, T_1 Thrust and the Mishmi Thrust. The river also gets widened in this area. Towards western side in the lower reach, the shape of the basin is elongated and appears to be controlled by F_1 and subsurface faults present in the region (Fig. 1). From the fig. 1 and 3, it is evident that the shape of the basin is controlled by the influence of the faults present in the area.

4.7 Transverse Topographic Symmetry

Transverse topographic symmetry [10] is defined as T= D_a/D_d, where D_a is the distance from the midline of the drainage basin to the midline of the active meander belt and D_d is the distance from the basin midline to the basin divide. For perfectly symmetric basin T=0 and it approaches 1 as asymmetry increases. For this study we have calculated two transverse topographic symmetry profiles as marked with red line in fig. 3. These two profiles which fall in the valley showing transverse topographic symmetry values T_1= 0.91 (D_d= 7089.86 m and D_a= 6441.48m) and T_2= 0.92 (D_d= 2212.32 m and D_a= 2033.46m) inferring a north and northeastward tilt of the river basin.

5. DISCUSSION

This part of the NE India is the juncture of the two tectonic domains [19]: 1) the eastern syntaxial band (Mishmi Massif) and 2) the

Table 1. Knick points with down throws measurement

Longitudinal Profile	Knick Points	Down throw (metres)	Structural discontinuity
LP1	KP1	80	Tidding Suture
	KP2	30	Mishimi Thrust
	KP3	120	Naga Thrust
	KP4	30	F1 fault
LP2	KP5	50	T1 thrust
	KP6	120	Naga Thrust
	KP7	30	F1 fault

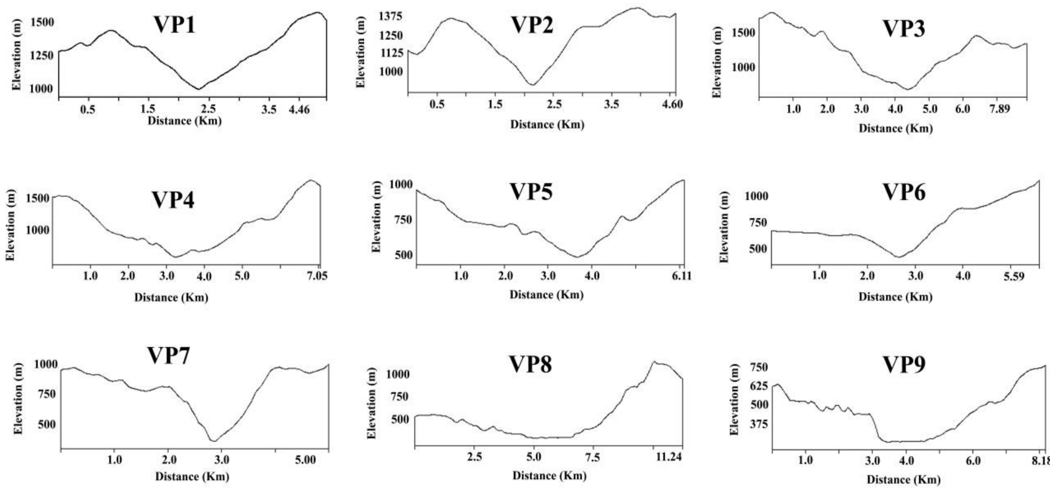

Fig. 6. Valley profiles measured from the right bank (represented by the left side of the profiles) to the left bank (represented by the right side of the profiles) in Noa-Dihing River. Location of the valley profiles are indicated in Fig. 3

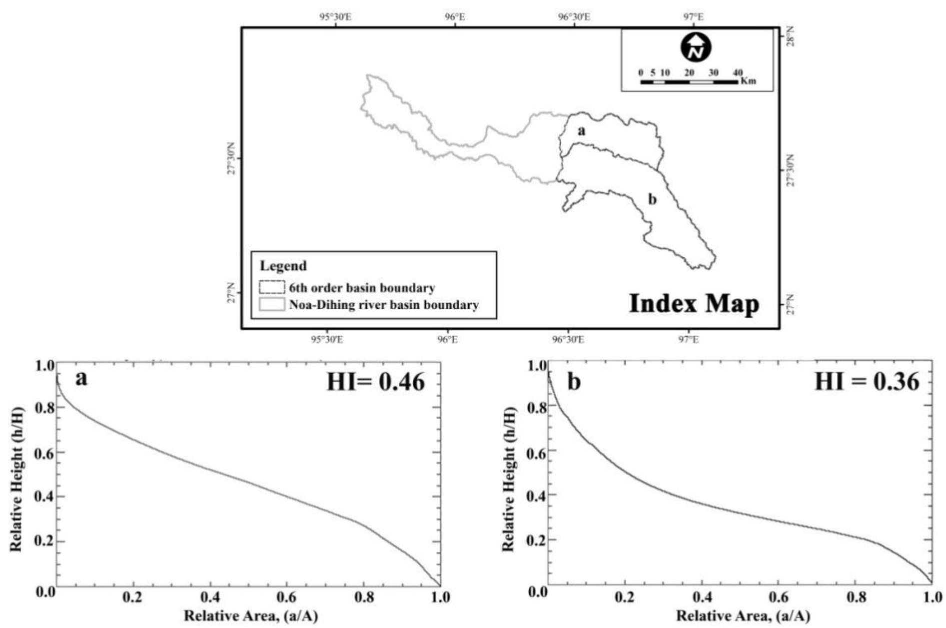

Fig. 7. Hypsometric plots for 6th order sub-basins of Noa-Dihing River derived from 3arc second SRTM DEM

Indo-Burma mobile belt (Naga-Patkai Ranges) along with the plains of Brahmaputra River basin. The Noa-Dihing basin falls on both of the tectonic domains. Morpho-dynamic parameters give the idea why the river behaves differently in it journey to the Brahmaputra.

The right bank of the river is possessing higher relief (> 4000 meters in few places) as compared the left bank (up to 3000 meters). This difference in relief and slope is primarily due to the tectonic processes with subordinate lithological composition. The sub-basins of the right bank of the river show convex upward hypsometric plot and higher HI values indicating youthfulness of the terrain which possibly reflect the tectonic activity within the various structural elements present in the area. The seismic events of lower

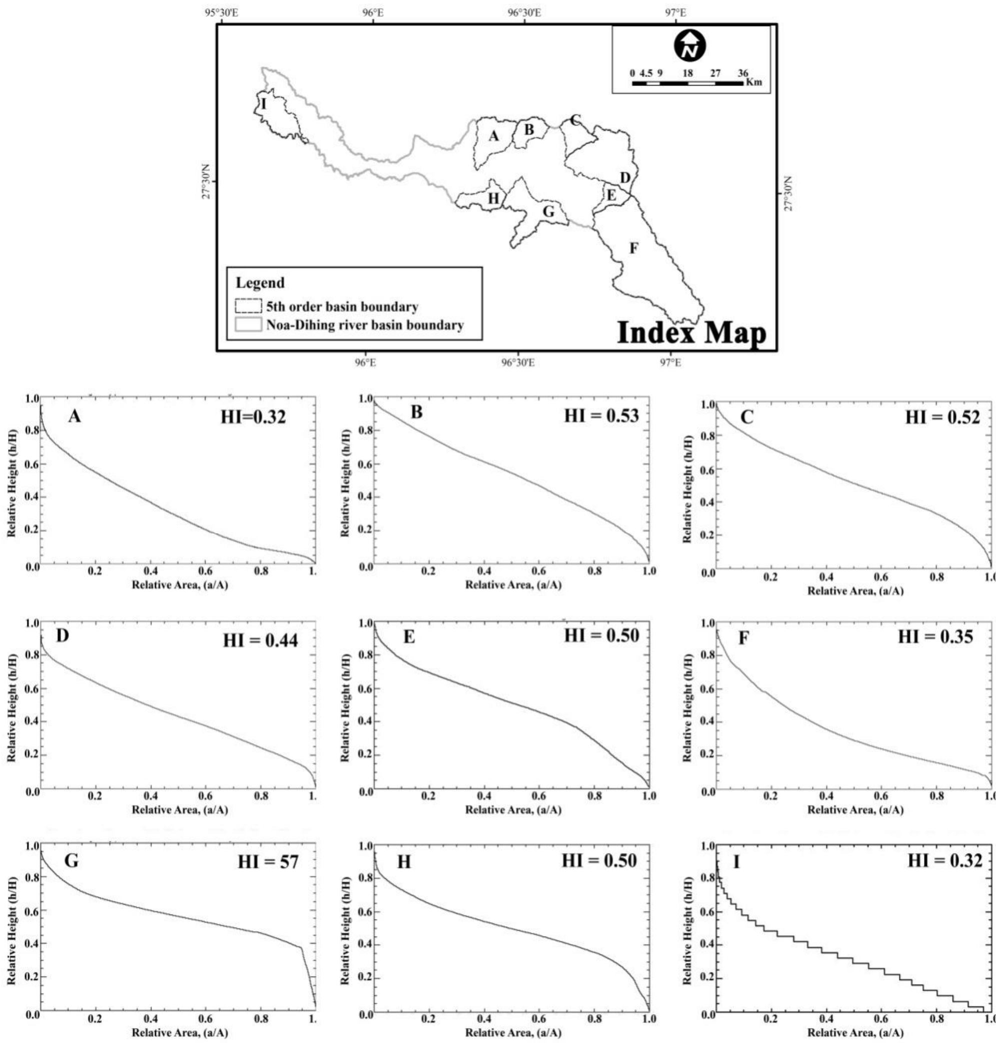

Fig. 8. **Hypsometric plots for 5th order sub-basins of Noa-Dihing River derived from 3arc second SRTM DEM**

to moderate magnitude occurred in the area reflects the active tectonic activity in the area (Fig. 1). The drainage system of this part of the basin shows rectangular type inferring the influence of the tectonic elements in the river basin.

The hypsometric curves of the foothills region and valley part concave downward, lower values of HI and gentle gradients which together infer eroded or horizontal landform. The channel at the downstream part of the river shows dendritic pattern due to the very gentle gradient in the flood plains.

The valley profiles across the Noa-Dihing River show steeper right bank and gentle left bank at the upstream while they show gentle right bank and steeper left bank at the downstream areas. This infers that the basin is tilting towards south and south-west in the upstream mountainous areas while it appears that the shift of the river in the alluvial plains to the right bank is also controlled by the F_1 subsurface fault which is close to the right bank catchment boundary trending NW-SE (Fig. 1). Since in the plains the river is shifting towards the right bank, natural levees formed along the left bank which gives higher relief to the left bank in this part of the basin.

The basin asymmetry factors infer that the Noa-Dihing River basin is an asymmetrical basin and shape is structurally controlled. The transverse topographic symmetric study also confirmed the highly tilted basin towards north in the valley part indicating the influence of the subsurface F_1 fault. The longitudinal profiles show number of knick points along the river where various thrusts and subsurface faults have cut across the channel.

6. CONCLUSIONS

The concluding inference from the study is that the Noa-Dihing River is dominantly tectonically controlled. The development of the geometry of the river basin is being controlled by two tectonic domains, namely, the Mishimi Massif and the Naga-Patkai Range. The results show that even in the alluvial plains the river is controlled tectonically and is being shifted towards north and north-east due to the influence of the subsurface fault (F_1). The results also establish the lithological control over the river geometry. The study indicates that the morpho-dynamics parameters can be derived from space born SRTM DEM data and the results clubbed with seismology, geology and structural data can be used to study the active tectonics of a region.

ACKNOWLEDGEMENTS

The Authors are thankful to the Department of Geological Sciences, Gauhati University, Assam, India for providing the necessary laboratory support to carry out the study. We acknowledge the services provided by the USGS website for source of the SRTM DEM data Landsat 8 data and the earthquake catalogue. We are also thankful to the ISC portal and NEIST, Jorhat, Assam, India for providing earthquake catalogue.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/22347