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Research Article

MORPHOTECTONIC STUDIES OF THE TUIRINI DRAINAGE BASIN: A REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM PERSPECTIVE

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ABSTRACT
Morphotectonic indices have been proven to be useful tools in evaluating the degree and nature of tectonic activity in a specific area, and are commonly used to identify areas affected by recent tectonic deformation. Remote sensing and GIS techniques are considered to be suitable for identifying and quantifying the effects of neotectonic activity over a large area. The analysis has been carried out by using remote sensing and GIS tools in order to understand the ongoing tectonic changes of the terrain in response to neotectonic activities. The study area exhibits complex topography as a result of folding and faulting of sedimentary sequences, and the drainage system is controlled by underlying lithology and geological structures. The basin is elongated in shape due to the combined effects of thrusting and folding in the area. As a whole the terrain is tilted towards the west with asymmetric nature of the basin. The overall results reflect that the Tuirini drainage area is tectonically active in nature.

Keywords: *Morphotectonic Indices, Neotectonism, GIS, Tuirini River, Mizoram*

INTRODUCTION
The Himalayan mountain belt was evolved during the late Cenozoic deformation caused by convergence collision between the Indian and the Eurasian plates (Molnar and Tapponnier, 1975), which represents one of the youngest and largest foreland belts in the world. The entire northeastern region of India is a part of the Himalayan mountain belt, which is tectonically active zone due to collision between the two arcs, the Himalayan arc in the north and subduction zone along the Indo-Burma arc in the east (Kayal, 1996 & 1998; Molnar and Tapponnier, 1975; Baruah *et al.*, 1967).
The state of Mizoram is one of the seven states in the northeast India. The terrain is tectonically active, geologically unstable and hence comprises of younger sedimentary strata. The Tertiary rock sequences are complexly folded and faulted due to neotectonic activities in this region. Tectonically, Mizoram forms a part of the Patkai-Naga-Lushai-Arakan-Yoma fold belt (Nandi *et al.*, 1983) and is generally referred to as the Indo-Burmese fold-thrust belt. The folded belt of Mizoram comprises a repetitive succession of argillaceous and arenaceous strata, which are thrown into a series of approximately N-S trending, sub-parallel, arcuate elongated, doubly plunging folds arranged en-echelon with asymmetric and tight anticlines and broad synclines with a slight convexity towards the west (Ganju, 1975; Ganguly, 1975 & 1983; Shrivastava *et al.*, 1979). These structures are offset by numerous faults and thrusts and comprise Early Miocene and Late Paleocene clastic sediments of Surma Group (Ram and Venkataraman, 1984).
Tectonic activity plays an important role in the development of drainage basin morphology. Analysis of a drainage basin in response to the tectonic processes can provide an insight into the past and recent deformational events of the region. Drainage networks are the most active and sensitive elements which can be used as a powerful tool to understand the neotectonic activities of an area. Morphotectonics deals with the landscape morphology that has evolved as a result of past or recent tectonic activity. An analysis of active structures can be done by using morphotectonic indices, which are sensitive to rock resistance, climatic changes and tectonic processes resulting into landscape evolution. The information about tectonic history of an area can be retrieved through analysis of topographic maps, aerial photographs, satellite data and quantification of different morphotectonic indices (Keller, 1986). Remotely sensed data

and geographic information system (GIS) techniques are widely applied for the studies of tectonic geomorphology. Recently, geoinformatics has become one of the most widespread advance technology for the analysis of topography and assessment of crustal deformation or movement.

Therefore, an attempt has been made to understand the tectonic status of the Tuirini drainage basin through remote sensing and GIS techniques.

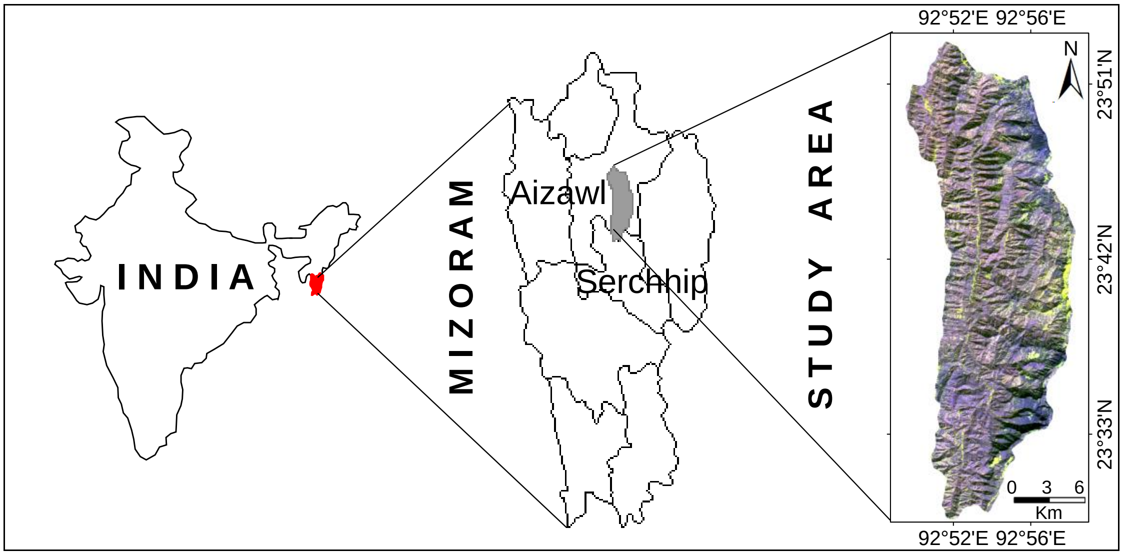

Figure 1: Location Map of the Study Area

Location and Geotectonic Setting of the Study Area

The study area falls in two districts of Mizoram viz. Aizawl and Serchhip at longitudes between 92º49´34´´ and 92º58´22´´ and latitudes between 23º28´37´´ and 23º53´20´´ (Figure 1). The basin covers an area of about 420.07 sq.km occupied by structural hills and elevation of the study area varies from 78 m to 1905 m above mean sea level (Figure 3). The drainage basin is bounded on the east by the river Tuivawl and west by the Tuirial river. The study area is drained by Tuirini river which is initially flows towards the north, then turns westward and finally joins the Tuirial river (Figure 2a). The Tuirini drainage system shows well developed drainage networks ranging from the first to six order streams. The climate of the study area is characterised by humid tropical. The area receives an average annual rainfall of about 2300 mm as it is under the direct influence of south-west monsoon. The average maximum and minimum temperatures of the basin area are about 30°C and 10°C, respectively.

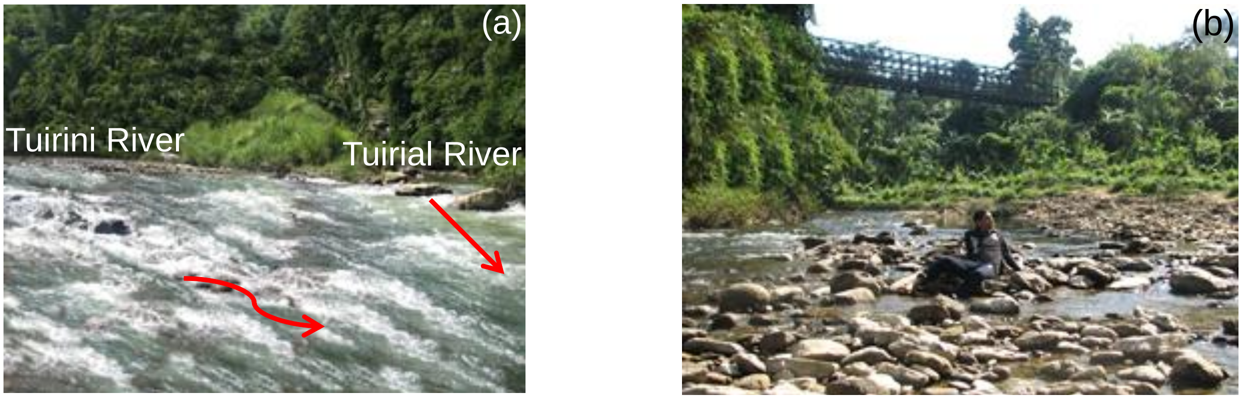

Figure 2: Field Photograph Showing (a) Junction of Tuirini and Tuirial Rivers; (b) Deposition of large Amount of Sediments (Gravels and Pebbles) along the Tuirini River near Tuirinikai Village

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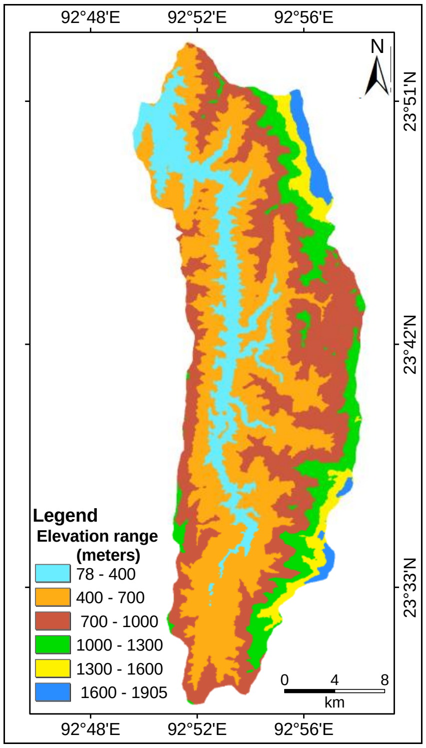

Figure 3: Elevation Map

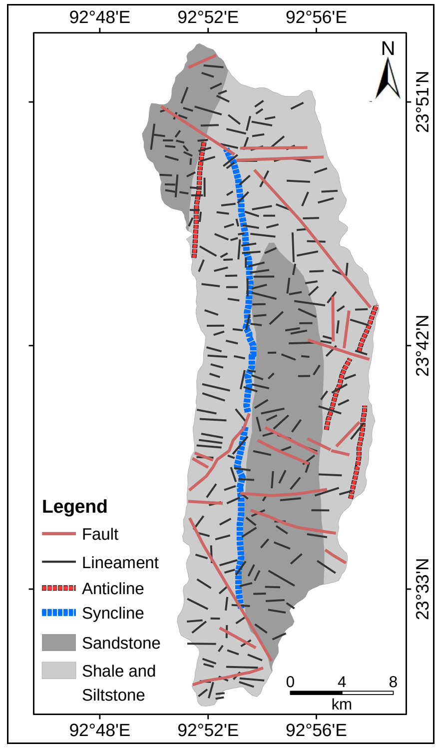

Figure 4: Geological Map

As the study area is the part of the Indo-Burma region, hence, the landforms form the part of the active tectonic belt. The basin is structurally very complex, with a number of faults and lineaments (Figure 4). The rocks have been folded into a series of longitudinal en-echelon anticlines and synclines. The anticlines are very tight, asymmetric while the synclines are narrow valleys. Most of the anticlines and synclines are doubly plunging. The main course of the river and its tributaries are controlled by lineaments. Geologically, the basin area is occupied by the Tertiary succession of Surma Group that ranges from the Lower Miocene to Middle Miocene age. The study area comprises of sandstones, shales, siltstones and their various intermixtures in varying proportions, which were deposited in deltaic to shallow marine environment. These sedimentary rocks are subjected to tectonic activities, resulting in the present configuration of topography that is anticlinal hills and synclinal valleys.

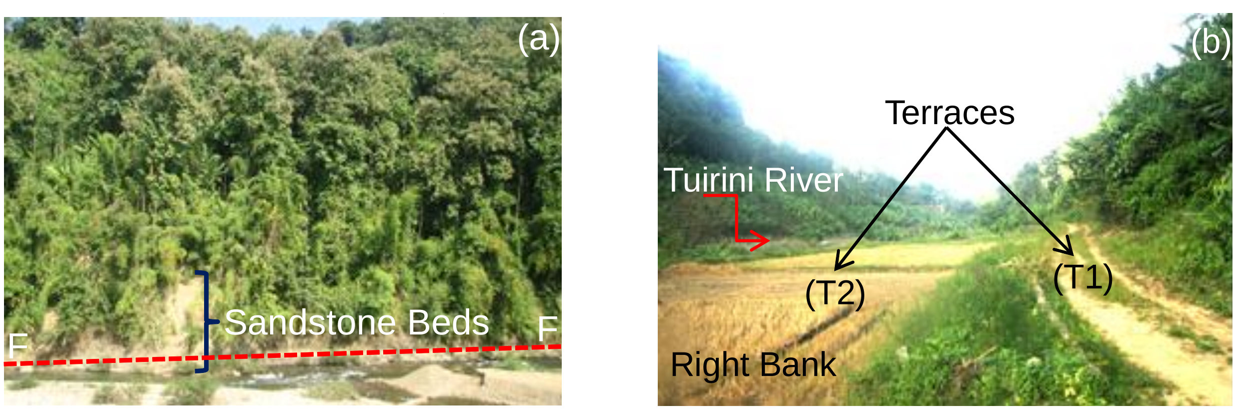

Figure 5: Field Photograph Showing (a) The Sandstone Beds and Fault (F-F) Controlled River Course in the Lower Part of the River. At Places Sediment Deposits (Valley Fills) are also Observed on Left Bank; (b) Synclinal Valley with River Terraces in the Middle Reaches of the Tuirini River

MATERIALS AND METHODS

Geocoded Indian Remote Sensing satellite data (IRS -1D, LISS III) was obtained for 055 row and 113 path of 04th February, 2001 with 23.5 m spatial resolution on 1: 50,000 scale and Survey of India (SoI) toposheets (No. 84/A13, 84/A14 and 84/A15) on 1: 50,000 scale have been used for the present study. ASTER Global Digital Elevation Model with 30 m resolution tile number ASTGTM2_N23E092 was also utilized for this study. All the data set were geo referenced with Zone 46 N and WGS - 84 datum of Universal Transverse Mercator (UTM) projection system so that errors can be minimized in spatial analysis. The morphotectonic indices were estimated based on mathematical formulae proposed by Muller (1968), Pike & Wilson (1971), Hack (1973), Bull & McFadden (1977) and Cox (1994). All the measurements have been carried out in GIS platform using Arc GIS-10.2 version. Geological map has been prepared from the existing geological map of the Mizoram (Ganju, 1975; Ram and Venkataraman, 1984) and also from the field investigations in the area. For better accuracy of the thematic maps, ground truth verification has been done in key areas.

RESULTS AND DISCUSSION

Different morphotectonic indices viz. basin elongation ratio, drainage basin asymmetry, hypsometric integral, transverse topographic symmetry factor, channel sinuosity, valley floor width to valley height ratio, stream length gradient index and mountain front sinuosity have been calculated and there results are interpreted below.

Basin Elongation Ratio

The basin elongation ratio (Re) is defined as the ratio of the basin area (A) to the maximum basin length (Lb), i.e. $Re = (1.128 \sqrt{A})/ Lb$ (Bull and McFadden, 1977). This index reflects the shape of the drainage basin, where higher values represent circular shape in tectonically undisturbed environment while lower values indicate elongated shape associated with tectonically active areas. The Re values < 0.50 is characteristic of tectonically active basins, Re values ranging between 0.50 - 0.75 show slightly active basins and Re values > 0.75 reflect inactive basin settings (Bull and McFadden, 1977). The Re values computed for the Tuirini basin and its sub-basins range between 0.35 to 0.73 (Figure 6 and Table -1), suggest that the study area is slightly active to tectonically active.

Drainage Basin Asymmetry

Drainage basin asymmetry (AF) analysis helps in identifying neotectonic activity in areas underlain by weakly consolidated Quaternary alluvium and is expressed as $AF = (Ar/At) * 100$ (Cox, 1994), where Ar is the area of the basin to the right of the trunk stream that is facing downstream and At is the total area of the drainage basin. It is used to detect the presence or absence of regional tectonic tilting at drainage basin scale as well as larger areas (Hare and Gardner, 1985; Keller and Pinter, 2002). In a stable setting environment AF values is ~50, while AF values higher or less than 50 indicates tectonic tilting (Keller and Pinter, 2002).

In the present study, the calculated values of AF range from 30.16 to 67.42 (Table -1) for sub-basins indicate tectonic tilt whereas AF value for the Tuirini basin is 72.26 suggests tectonic tilt towards the west (Figure 7).

Hypsometric Integral

The hypsometric integral describes the distribution of elevations of a land surface, which is related to the degree of dissection of a landscape and also it is a powerful tool to differentiate between tectonically active and inactive regions (Keller and Pinter, 1996). The hypsometric integral (HI) is estimated by using the Pike and Wilson (1971) method.

The relationship is expressed as $HI = (H_{mean} – H_{min})/ (H_{max} – H_{min})$, where H_{mean} is the mean elevation, H_{max} and H_{min} are the maximum and minimum elevations, respectively. High values of the HI reflect that most of the topography is high relative to the mean characterized by smooth upland landform surfaces with deeply incised streams, indicating a youthful stage of geomorphic development. Intermediate to low HI values are associated with more evenly dissected drainage basins, representing a mature stage of basin development (Keller and Pinter, 2002; Strahler, 1952). In the study area, the HI values vary between 0.37 to 0.89 (Figure 7 and Table -1), suggest the mature stages of landscapes development and the drainage areas are associated with neotectonic activities.

Table 1: Estimated Re, AF and HI Values for the Tuirini Basin & its Sub-Basins

Sub-Basins Name	Area (A) sq.km	Basin Elongation Ratio (Re)	Drainage Basin Asymmetry (AF)	Hypsometric Integral (HI)
Maudarh	51.80	0.63	57.67	0.58
Khuai	21.76	0.72	55.08	0.44
Tuizal	8.87	0.60	61.88	0.41
Lungding	12.68	0.63	63.09	0.49
Chal	9.79	0.64	42.97	0.64
Saibual	22.58	0.69	66.42	0.89
Maltliak	10.46	0.65	32.47	0.42
Ramri	11.67	0.68	54.96	0.84
Kaihzawl	34.83	0.67	45.19	0.45
Sathang	4.87	0.62	43.92	0.41
Thangzai	5.58	0.35	37.71	0.48
Kang	35.57	0.71	58.52	0.50
Tuikhan	65.65	0.73	37.02	0.38
Sakei	8.77	0.71	38.14	0.51
Maumit	5.86	0.72	44.09	0.51
Dam	13.93	0.70	38.65	0.53
Inran	24.82	0.63	42.76	0.47
Inrum	27.73	0.64	67.42	0.37
Minpui	7.58	0.68	40.10	0.57
Damdiai	9.84	0.67	39.95	0.47
Chhimluang	20.68	0.69	30.16	0.49
Phekphe	4.75	0.54	56.28	0.60
Study area	420.07	0. 47	72.26	0.42

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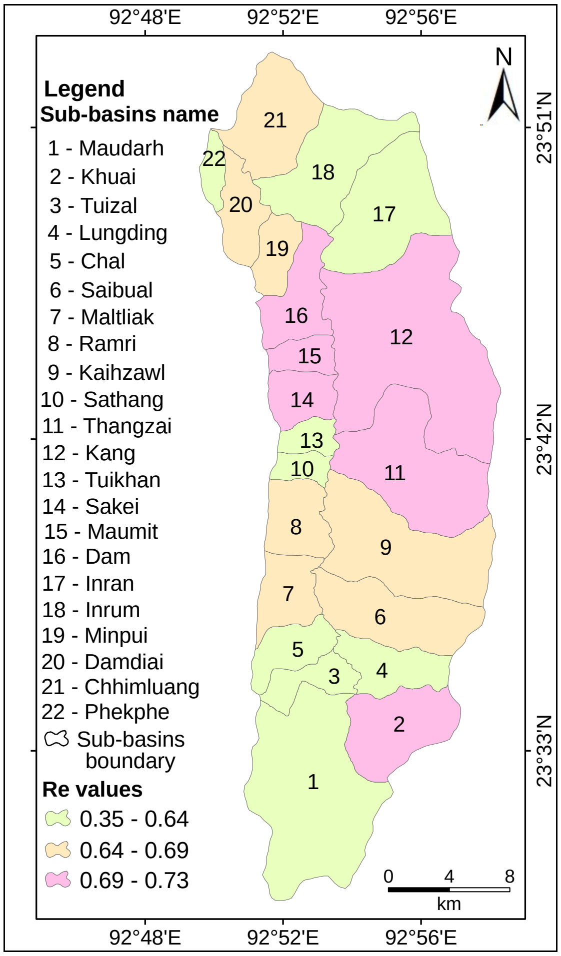

Figure 6: Elongation Ratio Map

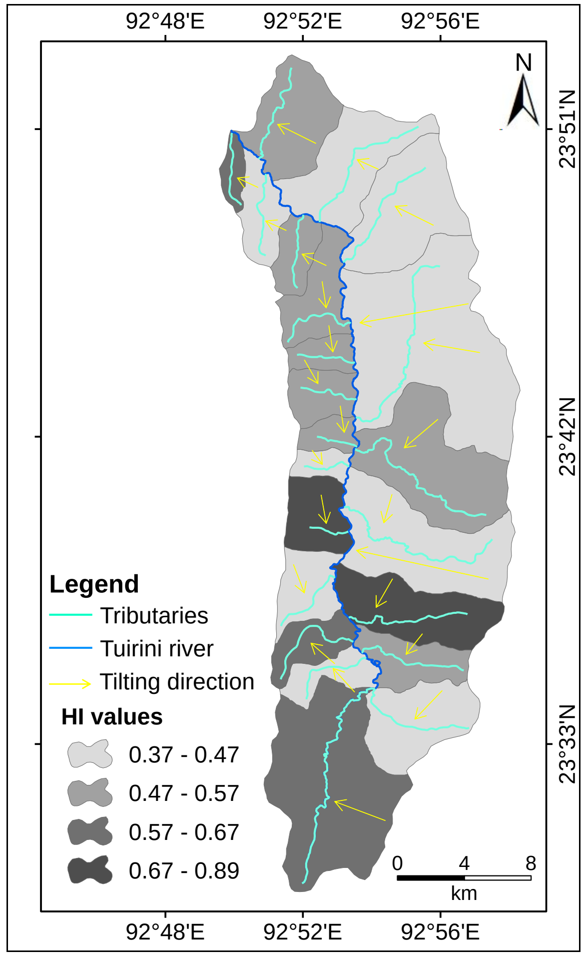

Figure 7: HI Map and Tilting Direction of Sub-Basins

Table 2: Computed T, S and Vf Values of the Tuirini Basin

Segments Number	Transverse Topographic Symmetry Factor (T)	Channel Sinuosity (S)	Valley Floor Width to Valley Height Ratio (Vf)
1	0.46	1.10	0.07
2	0.20	1.38	0.08
3	0.25	1.77	0.10
4	0.48	1.23	0.11
5	0.52	1.13	0.13
6	0.44	1.14	0.16
7	0.43	1.24	0.19
8	0.37	1.57	0.22
9	0.38	1.29	0.27
10	0.41	1.30	0.32

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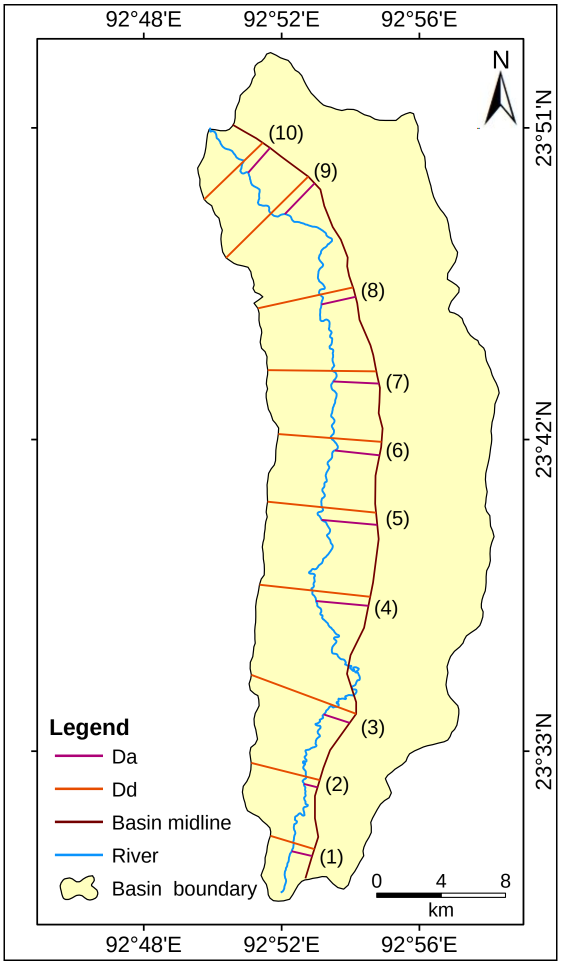

Figure 8: Transverse Topographic Symmetry Map

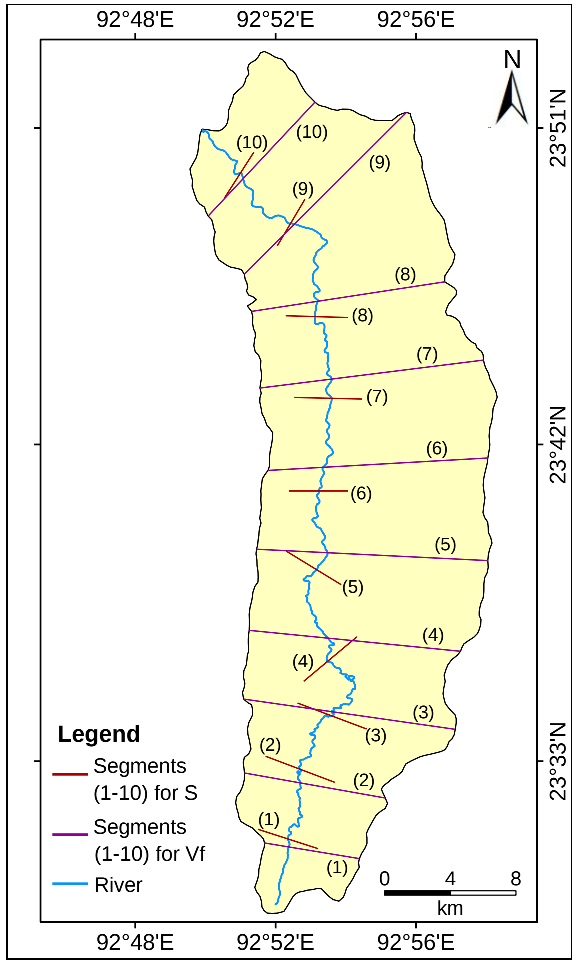

Figure 9: Channel Sinuosity and Vf Map

Transverse Topographic Symmetry Factor

The transverse topographic symmetry factor (T) of a drainage basin is expressed by the ratio as T = Da/ Dd (Cox, 1994), where Da is the distance from the midline of the drainage basin to the midline of the active meander belt and Dd is the distance from the basin midline to the basin divide.

It is a vector that has direction and magnitude and also used to determine the possible tilt direction. The value of T varies between zero and one, for perfect symmetric basin T is equal to 0 as the asymmetry increases T increases and approaches to value of 1.0 (Cox, 1994; Keller and Pinter, 2002).

In order to determine T values of the Tuirini basin, the basin area is divided into ten segments numbered from 1 to 10 by the straight line then the value of T calculated for each segment as shown in figure 8. The estimated T values in the study area vary from 0.20 to 0.52 (Table - 2), indicating an asymmetric nature of the basin.

Channel Sinuosity

Tectonics can seriously affect river behaviour and the channel sinuosity is widely used to detect the tectonic changes along the course of the river. In response to uplift, a river changes its channel pattern by increasing the sinuosity or by changing channel pattern to straight or braided (Burnett and Schumm, 1983). A river meanders, when the straight line slope of the valley is too steep for equilibrium, the sinuous path of the meanders reduces the slope of the channel. Any tectonic deformation that changes the slope of a river valley results in a corresponding change in sinuosity to maintain the equilibrium channel slope (Keller and Pinter, 2002).

Channel sinuosity (S) is a dimensionless ratio, which is defined as the ratio of the stream length (SL) to the valley length (VL) and computed by using the formula (Muller, 1968) i.e. S = SL/ VL.

The sinuosity index value close to 1.0 indicates straight course, whereas values between 1.0 and 1.5 represent sinuous river shape and S value greater than 1.5 suggests meandering course (Muller, 1968).

For determination of channel sinuosity, the river channel is divided into ten segments numbered from 1 to 10. The channel sinuosity values for Tuirini river are measured at different sectors (Figure 9) varied between 1.10 to 1.77 (Table 2), indicating sinuous character of river path, as segments values are greater than one.

The channel segments no. 3 and 8 are characterized by high sinuosity values as compared to other segments show meandering nature of river course.

Figure 10: Field Photograph Showing (a) Sinuous Course with Steep Vegetated Valley Side Scarp and Point Bar Deposit in the Middle Reaches of the River. This Point Bar Deposit is Composed of Medium to Coarse Grained Sand on Right Bank (Red Arrow Indicates Flow Direction); (b) View of ~ 30 m High Waterfall along the Seling-Keifang Road

Valley Floor Width to Valley Height Ratio

Valley floor width to valley height ratio (Vf) is a geomorphic index which reflects the degree of maturity of a river valley and also helps to identify the relative rate of tectonic upliftment of the mountain front (Kale and Shejwalkar, 2008; Bull and McFadden, 1977; Bull, 1977a).

It can be expressed as Vf = 2Vfw/ [(Eld – Esc) + (Erd – Esc)], where Vfw is the width of valley floor, Eld and Erd are the elevations of the left and right valley divides, respectively and Esc is the elevation of the valley floor (Bull and McFadden, 1977).

This index is used to quantify the differences between broad-floored canyons (U-shaped), with relatively high values of Vf and V-shaped valleys with relatively low values.

V-shaped valleys are formed in more tectonically active areas, while U-shaped valleys are formed in less active settings.

High values of Vf are associated with low uplift rates so that streams cut broad valley floors whereas low values of Vf correspond to deep valleys of actively incising streams and are commonly associated with high uplift rates (Keller and Pinter, 1996; Bull and McFadden, 1977).

In the present study, the values of Vf were determined along the Tuirini river at ten locations viz. 1 to 10 as shown in figure 9 and there values range between 0.07 to 0.32 (Table 2), which represent deep, narrow, V-shaped valleys and also indicate ongoing incision and gradual upliftment in the area.

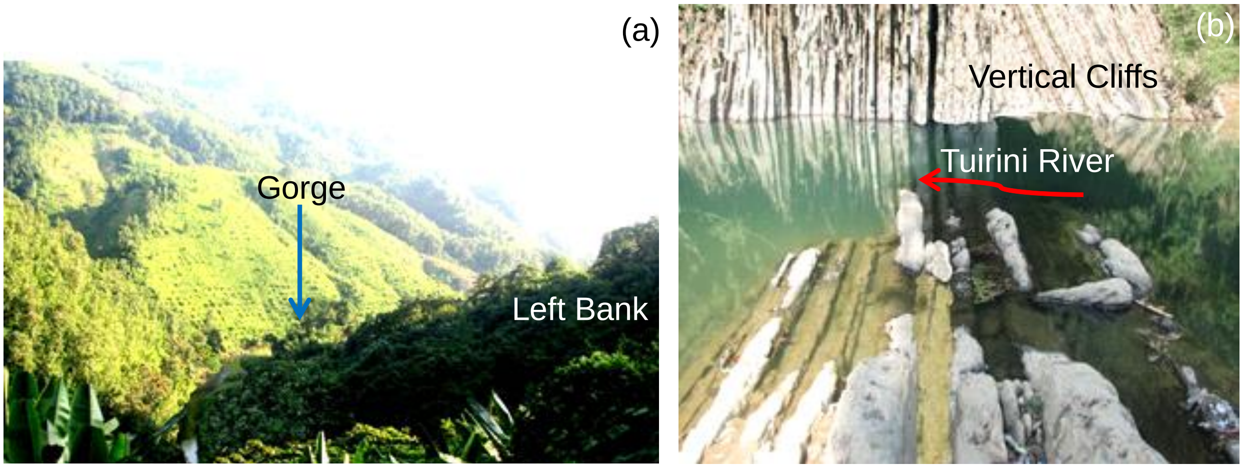

Figure 11: Field Photograph Showing (a) Deep and Narrow Gorge with Steep Valley Side Slopes in the Upper Reaches of the Tuirini River; (b) Incision of River Bed in the Lower Reaches of the River. Vertical Cliff Faces can be Seen on Right Bank of the Tuirini River

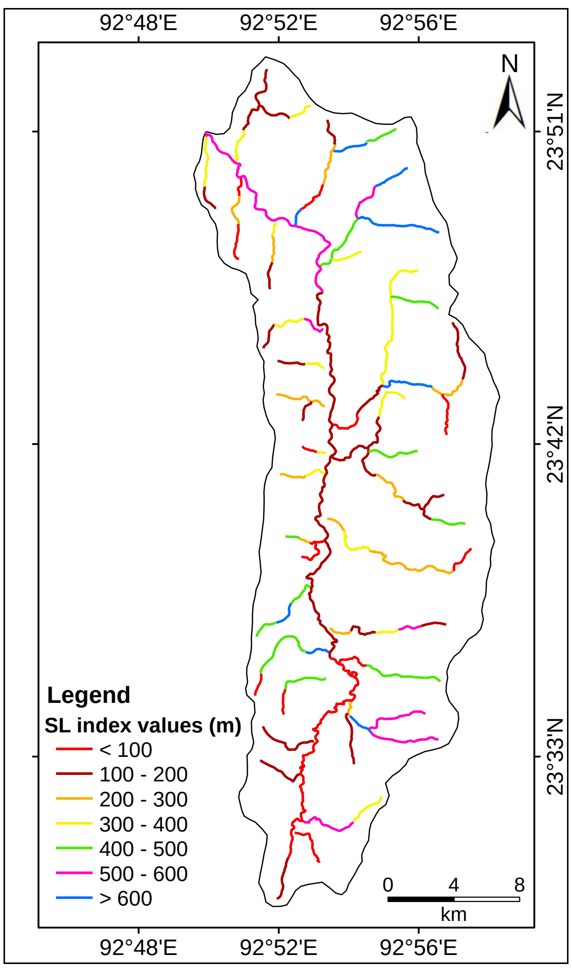

Figure 12: Stream Length Gradient Index Map

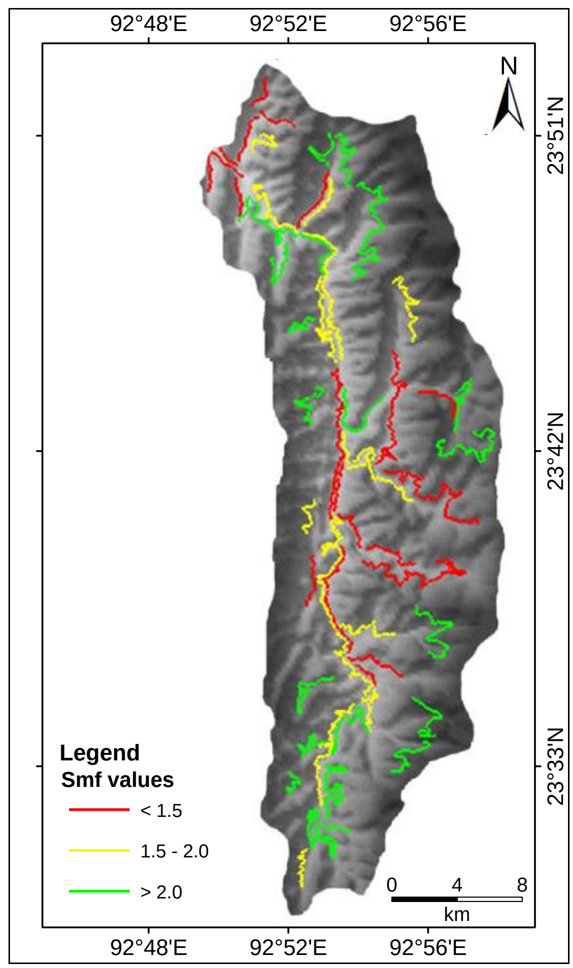

Figure 13: Mountain Front Sinuosity Map

Stream Length Gradient Index

Stream length gradient index (SL) is a powerful tool to measure channel slope changes and allows the evaluation of relationships among possible rock resistance, topography and tectonic activities in a region (Hack, 1973; Keller and Pinter, 2002). It is defined as the product of the slope of a reach multiplied by the distance from the headwater divide and mathematically it can be expressed as $SL = (\Delta H/\Delta L) * L$, where $\Delta H/\Delta L$ is the stream gradient of the reach where the index is computed, ΔH represents the change in elevation of the reach, ΔL is the length of the reach and L is the total channel length from the midpoint of reach where the index is calculated upstream to the highest point on the channel (Hack, 1973). High SL index values reflect where rivers and streams flow over the hard rocks or areas with high tectonic activity whereas low SL values indicate relatively low tectonic activity and less resistant or soft rock types (Hack, 1973; Keller and Pinter, 2002).

The SL index is calculated for the Tuirini river and its tributaries along the courses of the streams. In the study area, values of SL index ranging from 15 m to 727 m and are grouped into seven classes (Figure 12). The variations of SL index values across the drainage basin might be due to the lithological variations or influenced by tectonic activity.

Mountain Front Sinuosity

Mountain front sinuosity (Smf) is used to discriminate between tectonically active mountain fronts from inactive fronts and this index also reflects the balance between erosional forces that tend to cut the embayment into a mountain front and tectonic forces that tend to produce a straight mountain front coincident with an active range-bounding fault. It is defined as the ratio of the length of the mountain front along the foot of the mountain at the pronounced break of slope (Lmf) to the straight line length of the mountain front (Ls) and is expressed as $Smf = Lmf/ Ls$ (Bull and McFadden, 1977; Keller and Pinter, 2002).

A tectonically active mountain fronts typically show lower values of Smf, whereas higher values indicate relatively less active mountain fronts (Bull, 1977b & 1978; Bull and McFadden 1977; Burbank and Anderson, 2001; Keller and Pinter, 2002). According to Bull and McFadden (1977), Smf values lower than 1.4 reflect tectonically active fronts and Smf values ranging between 1.4 and 3.0 show less active fronts while Smf values greater than 3.0 are associated with inactive mountain fronts. In the present study, Smf values are measured for fifty nine mountain fronts (Figure 13) range between 1.07 to 2.88. Out of the 59 mountain fronts, 18 fronts show Smf value < 1.4, which suggest tectonically active, whereas for remaining forty one fronts show Smf value > 1.4 but < 3.0, fall in the slightly active category.

Conclusion

Quantitative analysis of a drainage basin using various morphotectonic indices have been found to be useful indicators in determining the present status of recent tectonic regime of the region. The present study also demonstrates the application of remote sensing and GIS techniques in evaluating neotectonic activity in a specific area.

Geologically, the study area is comprised of sedimentary rocks belongs to Surma Group. Structurally, this area is dominated by asymmetric valleys and most of the streams follow structural trend indicates structural control over the area for stream development. The sub-basins show more or less elongated shape associated with tectonic tilting, which might be due to uplifting or tilting imposes the asymmetry of the area.

The course of the Tuirini river represents sinuous nature with V-shaped valleys suggests active incision in the drainage area. The variations of SL index values across the drainage basin either due to the lithological differences or influenced by neotectonic activity in the area. The analysis of hypsometric integral reveals that the basin is characterized by rugged nature of topography and also representing a mature stage of basin development.

The overall analysed indices as well as field evidences indicate that the drainage area is tectonically active.

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