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Assessment of active tectonics in upper tapi sub-catchment using geo-spatial technology

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Abstract

Upper Tapi sub-catchment is a part of satpuda mountain range and located in between two states of India (Maharashtra and Madhya Pradesh). The area is dissected by no. of lineaments and faults. For the assessment of active tectonics we have used most conventional widely used geomorphic indices such as Basin asymmetry factor (AF), Basin shape index (BS), Hypsometric integral factor (HI), Transverse topographic symmetry factor (TTSF) and Stream gradient index (SL). The results derived from these geomorphic indices aggregated to produce relative active tectonics index (RAT) using GIS. The average of five calculated geomorphic indices were used to measure spatial distribution of RAT in study area. To define degree of RAT, we grouped RAT values in four classes, where class 1 (RAT 1 to <1.5) shows very high active tectonics, class 2 (RAT ≥ 1.5 to <2) shows high active tectonics, class 3 (RAT ≥ 2 to <2.5) indicates moderate tectonic activity and class 4 (RAT ≥ 2.5) indicates low tectonic activity. The results of RAT classes are well supported by the geomorphic evidences.

Keywords: Morphotectonics, SRTM, RAT (Relative Active Tectonics Index), Geomorphic Indices, Upper Tapi, Geomorphology.

Introduction

The Tapi River is the westerly flowing second large river in India. The catchment area of the Tapi River lies in Madhya Pradesh, Maharashtra and Gujarat state of India[1]. The river has its origin from the uplands of Satpura mountains near Multai town of Madhya Pradesh and exit in Arabian sea. The River is divided into 3 basins which are Uppar Tapi, Middle Tapi and Lower Tapi[1]. This study is on the sub-catchment of uppar tapi. Uppar tapi sub-catchment starts in the betul town to Burhanpur district in Madhya Pradesh state. This uppar tapi sub-catchment covers parts of Madhya Pradesh and Maharashtra states from which major part is in Madhya Pradesh State[1].

In the present study we made an attempt for the assessment of active tectonics in upper Tapi river sub-catchment using geo-spatial technology. Morphotectonics is the study of landforms formed by earth's tectonic processes. The drainage network in tectonically active area is susceptible to structural processes which results to form deviated rivers, river incision and asymmetric basin[2]. For the assessment of active tectonics geomorphic indices are useful as they can give insight about a area which is encountering slow and rapid tectonic activity[3,4].

An integrated approach using Structural, Geomorphological and Neotectonism is very supportive in evaluation of active tectonics[5]. Remote sensing technique is very important in providing spatial data for these indices. Spatial data helps to indentify and delineate structural and drainage features. The quantitative analysis of various geomorphic indices is accomplished by use of digital elevation model, topographical map and satellite imageries[6,7]. Quantitative analysis of geomorphic indices extracted from digital elevation model applied in the uppar tapi sub-catchment.

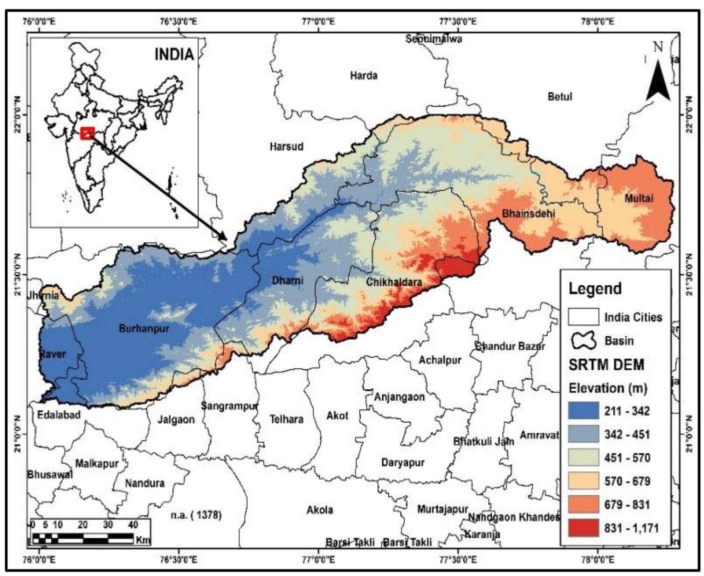

Figure-1: Location and Elevation map of study area.

Methodology

This study is completely based on the open source datasets available on web. SRTM (Shuttle Radar Topography Mission)

DEM (Digital Elevation Model) of 30m spatial resolution were used in this study. All the GIS datasets used in this study were geo referenced and projected using WGS-1984 datum and Universal Transverse Mercator (UTM) 43N zone to minimize errors in spatial analysis. Drainage network and basin boundary was extracted from SRTM DEM in GIS environment. Geology and Geomorphology map has been prepared using open source datasets available on Geological Survey of India web portal. The geomorphic indices calculation for all sub-basins and other mathematical calculation work has been carried out in GIS environment using ArcGIS and Q-GIS software. After calculation all sub-basins were divided into three classes and relative index for active tectonics is obtained by taking average of the geomorphic indices class and divided into four categories as per their relative tectonic activity.

Results and discussion

As the study area is part of satpuda hill range structurally it is very compelx with many lineaments and faults (Figure-2A). The main courses of streams are controlled by lineaments. Due to uneven topography flow direction of tributaries are uneven. There are two major faults observed namely tapi north fault and gawilgarh fault in NE and SE direction respectively. Drainage pattern is dendritic to sub-dendritic type in the study area (Figure-2C).

Geology: Most of the area is occupied by satpuda and sahyadri group of rocks of Late Creataceous-Paleocene age. The other groups of rocks are also important in geological sequence[8-9]. Pre-quaternary rocks in the study area are Deccan traps, Lameta and Gondwanas. The study area comprises of Basalt, Granite, Granite gneiss\ Migmatite, Quartzite, Alluvium, Sandstones, Limestones and their various intermixtures. Lithounits like Granites, Gneisses of Archean–Paleoproterozoic age forms base of the area followed by Gondwanas then overlain by Cretaceous Deccan traps and finally overspread by alluvium of Pleistocene period (Figure-2A).

Geomorphology: Based on the origin, the geomorphology of area is categorized into 3 parts, such as structural, Denudational and Fluvial (Figure-2B)[10]. Structural hills landforms of structural origin mostly observed in NE part of study area. Land forms of denudational origin represented by denudational hills and Pediments[11]. Active flood plain, Older flood plain, Older alluvial plain and Younger alluvial represents fluvial origin landforms[9].

Geomorphic Indices: Use of geomorphic indices to assess active tectonics rely on resistance in rock, climatic variation and tectonic processes. Geomorphic indices associated with drainage network are Basin asymmetry factor, Stream gradient index, Hypsometric integral factor, Transverse topography symmetry factor and Basin shape index. We measured different indices in the upper Tapi sub-catchment (8 sub-basins) and classified on the basis of index value of each geomorphic indices into different tectonic classes. These tectonic classes were summed, averaged to determine relative index of active tectonics (RAT). RAT index divided into four classes over all sub-basins (Table-3).

Basin asymmetry Factor (AF): AF identifies tilting and direction of tilting. It is measured using formula

$$F = \left(\frac{AR}{AT}\right) * 100 ,$$

where AR is area of right part of the basin and AT is the total area of the basin[2]. If AF value is 50 it means that there is no significant tectonic tilting or stable environment and if the value is less or high than 50 indicates lithological control or tectonic tilting[3]. In this study, AF values varies from 28.36 (UTSB2 Sub-basin) to 68.10 (UTSB8 Sub-basin). AF values were divided in three classes, where class 1 (AF≥57 or AF≤40) indicates high tectonic activity and asymmetric basin, Class 2 (AF≥53 to <57 or AF≥40 to ≤40) indicates moderate tectonic activity and Class 3 (AF≥48 to AF≤53) indicating low tectonic tilting or symmetrical basin.

Hypsometric Integral (HI): HI described as distribution of elevation of land related to degree of dissection of land[3]. HI is measured using the Pike and Wilson method[12]. The correlation is expressed using formula,

$$HI = \frac{(Hmean - Hmin)}{(Hmax - Hmin)}$$

Where, Hmean is mean elevation, Hmin minimum elevation and Hmax is the maximum elevation in the region. High HI values may be related to tectonically active region and low values to mature landscape which have been much eroded and less affected by tectonic activity. HI index values ranges from 0 to 113. In this study HI values ranging from 0.19 (UTSB6 Sub-basin) to 0.42 (UTSB1 Sub-basin). HI values with Convex and Concave hypsometric curves divided into three classes, where Class 1 (HI>0.4) with convex hypsometric curve indicates high tectonic activity, Class 2 (HI≥0.3 to ≤0.4) with concavo-convex or straight hypsometric curve indicates moderate tectonic activity and Class 3 (HI<0.3) with concave curve indicating low tectonic activity.

Transverse Topography Symmetry Factor (TTSF): TTSF of a basin expressed using formula,

$$T = Da/Dd$$

Where, Da is the distance between basin midline to midline of active meander Da is the distance from the basin midline to the active meander belt midline and Dd is distance from basin midline to and Dd is the distance from the basin midline to basin edge[2]. The values of T ranges between 0 to 1 where 0 indicates symmetric basin and values near to 1 indicates river asymmetry and flowing closely to basin margin may be due to tectonic activity[2,3]. In this study TTSF values varies from 0.17 (UTSB7 Sub-basin) to 0.52 (UTSB4 Sub-basin). These values were divided into three classes, where class 1 (TTSF > 0.4) indicates high tectonic activity, class 2 (TTSF > 0.2 to ≤ 0.4) indicates moderate activity and class 3 (TTSF ≤ 0.2) indicates low active tectonics or symmetrical basin.

Table-1: Aerial extent of Litho-units.

Age	Lithounit	Area (km^2)
Pleistocene	Alluvium	1411.21
Late cretaceous - Paleocene	Basalt	8635.00
Late Jurassic- early cretaceous	Sandstone	125.49
Late carboniferous - early permian	Conglomerate	72.10
Palaeoproterozoic	Granite	116.40
	Quartzite	0.03
	Graphite schist	0.13
Archaean- palaeoproterozoic	Granite gneiss/ migmatite	92.97
Total		10453.33

Table-2: Aerial extent of Geomorphologic units.

Geomorphological unit	Area (km^2)
Anthropogenic Terrain	8.62
Structural Hills	333.25
Denudational Hills	92.51
Plateau	6072.65
Pediment-Pediplain Complex	3123.40
Active Flood plain	5.79
Older Alluvial Plain	601.56
Younger Alluvial plain	71.49
Waterbody	144.06
Total	10453.33

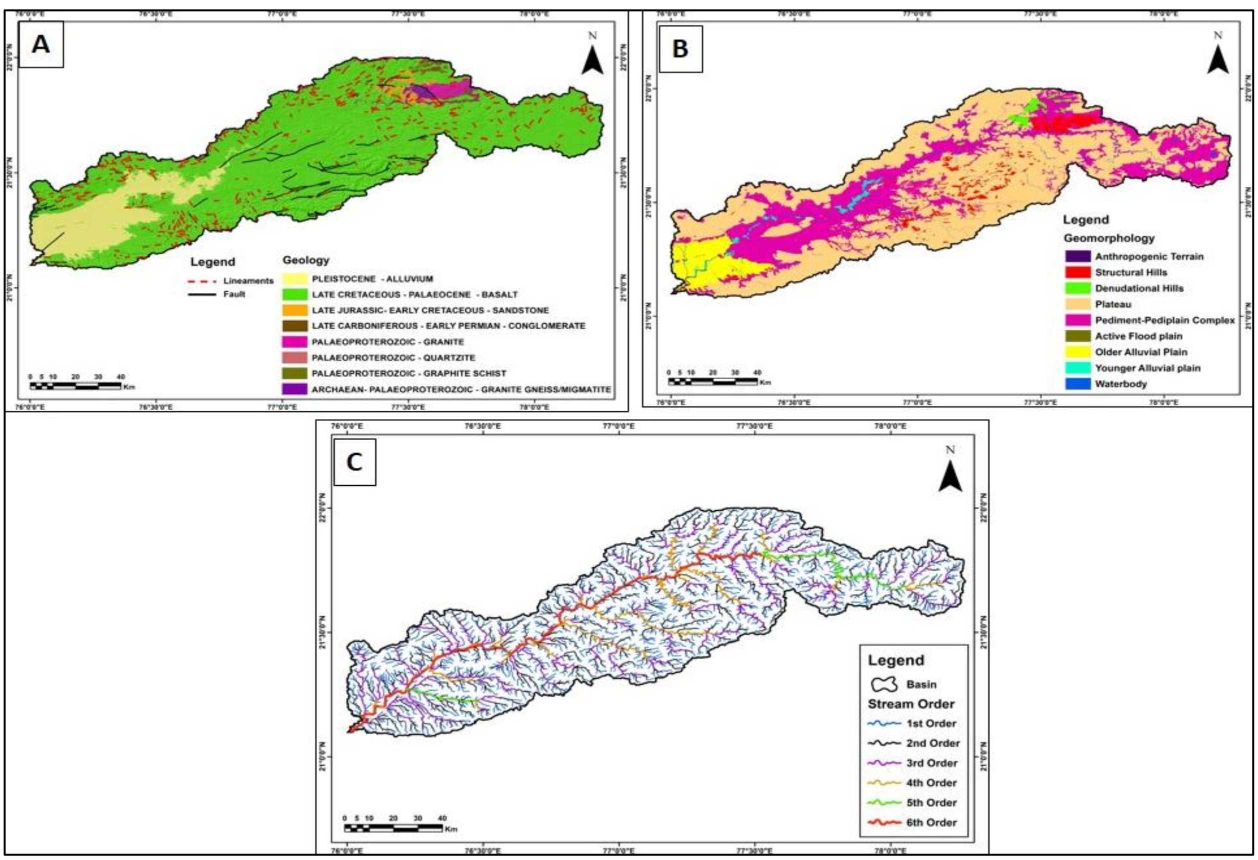

Figure-2: (A) Geology Map, (B) Geomorphology Map and (C) Stream Order map of Upper Tapi sub-catchment.

Stream Gradient Index (SL): Stream gradient index is very effective method to evaluate channel slope variation, rock resistance relationship and tectonic activities in a region[14]. SL index can be described by using mathematical formula,

$$SL = \left(\frac{\Delta H}{\Delta L}\right) * L$$

Where ΔH = (h1-h2) difference between highest and lowest elevation of a channel reach, ΔL = Horizontal distance of the given reach of the channel and L = total length of channel from its origin. Deviated and unstable river profiles may be due to tectonic, lithological and climatic factors[14]. A high SL index value indicates hard rock terrain or high tectonic activity area. Where low values of SL index indicates soft rock terrain or low active tectonics[15]. In this study we computed SL along streams and measured average value for all sub-basins. SL index values varies from 58.88 (UTSB8 Sub-basin) to 297.35 (UTSB2 Sub-basin). SL index values grouped into three classes, Class 1 (SL > 500) indicates high tectonic activity, Class 2 (SL> 250 to ≤ 500) indicates moderate tectonic activity and Class 3 (SL ≤ 250) indicates low tectonic activity[16].

Basin Shape Index (BS): Basin shape index (BS) expressed using mathematical formula,

$$BS = Bl/Bw$$

Where, Bl = Highest length of basin and Bw = Highest width of basin. Elongated shape of basin indicates young stage in tectonic activity and with continuous evolution and less tectonic processes elongated basin tends to evolve to circular in shape i.e. mature stage[17]. A high value of BS indicates elongated basin may be due to recent active tectonic processes and Low value indicates circular basin shape with less active tectonics. In this study BS values varies from 1.36 (UTSB8 Sub-basin) to 2.43 (UTSB3 Sub-basin). BS values grouped into 3 classes, Class 1 (BS > 1.5 to ≤ 2), Class 2 (BS > 1.5 to ≤ 2) Moderate activity and Class 3 (BS ≤ 1.5) indicates circular shape of basin or less active tectonic.

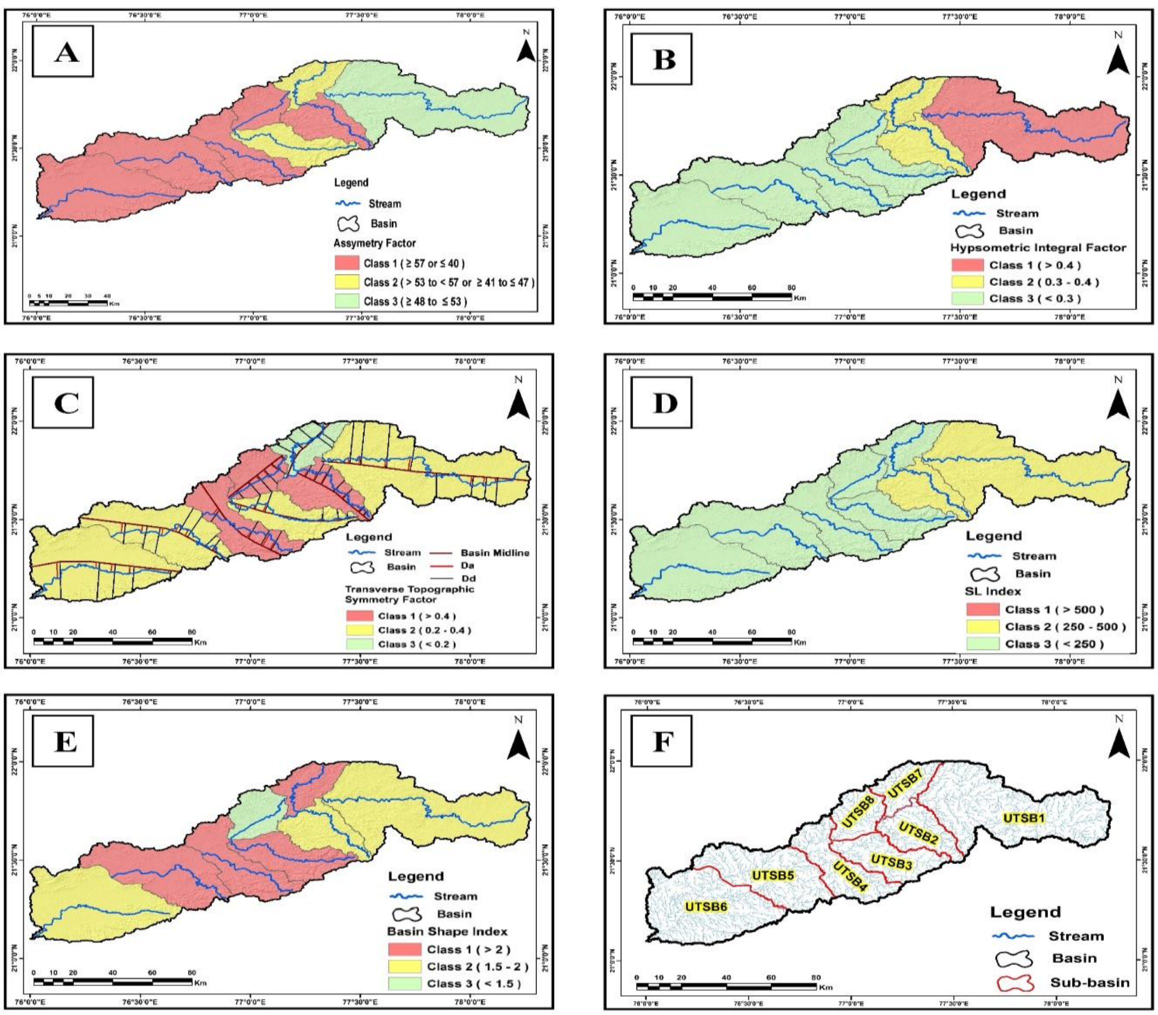

Figure-3: Basin classification as per geomorphic indices (A) Basin asymmetry factor, (B) Hypsometric integral factor, (C) Transverse topography symmetry factor, (D) Stream length gradient, (E) Basin shape index and (F) Upper Tapi sub-basins with sub-basin codes.

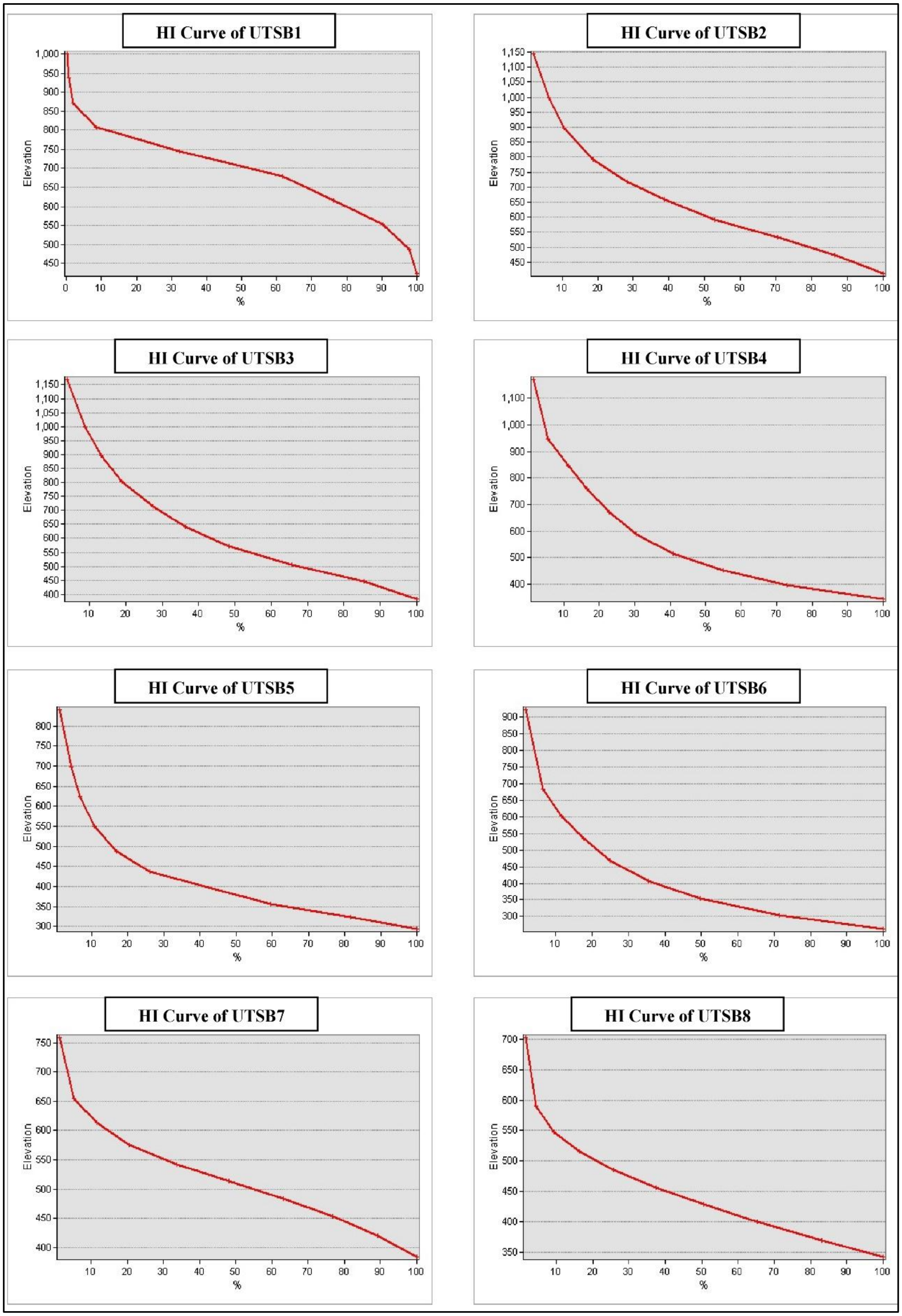

Figure-4: Sub-basin wise Hypsometric Curve (Elevation in Meters, % - Area in percentage).

Discussion: This study is to measure relative tectonic activity of a large area (10453.33) using geomorphic indices of several sub-basins. The average value of different classes from each geomorphic indices were combined to compute RAT. RAT index values have been grouped into four classes, where class 1 (RAT ≥ 1 to < 1.5) indicates very high tectonic activity, class 2 (RAT ≥ 1.5 to < 2) high tectonic activity, class 3 (RAT ≥ 2 to < 2.5) indicates moderate tectonic activity and class 4 (RAT ≥ 2.5) indicates low tectonic activity[15]. Spatial distribution of computed RAT classes shown in (Figure-6, Table-3). As per RAT index sub-basins UTSB2 and UTSB4 falls in class 2 occupying 17.98% (1879.05km^2) of the total area which indicate high tectonic activity in this region. Remaining sub-basins fall in class 3 indicating moderate tectonic activity occupying 82.02% (8574.29km^2) of the total area.

Table-3: Geomorphic Indices Classes and Relative Active Tectonics Index.

Sub-basin ID	Area (km^2)	AF	HI	TTSF	SL	BS	RAT	Class
UTSB 1	2867.55	3	1	2	2	2	2	3
UTSB 2	790.07	2	2	1	2	2	1.8	2
UTSB 3	890.34	2	3	2	3	1	2.2	3
UTSB 4	1088.97	1	3	1	3	1	1.8	2
UTSB 5	1562.62	1	3	2	3	1	2	3
UTSB 6	2131.60	1	3	2	3	2	2.2	3
UTSB 7	554.53	1	2	3	3	1	2	3
UTSB 8	567.65	1	3	1	3	3	2.2	3

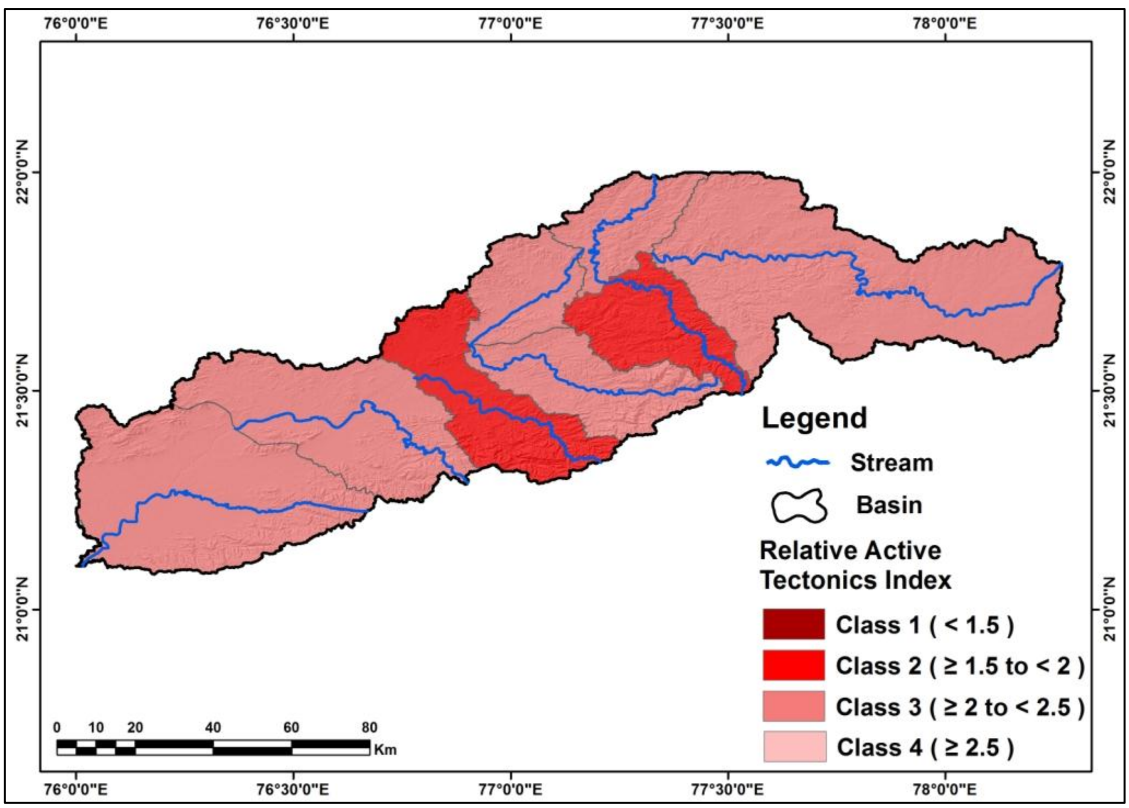

Figure-5: Spatial distribution of degree of relative active tectonics index in the study area.

Conclusion

The Remote sensing and Geoinformatics techniques found very useful extracting structural and drainage features. Quantitative analysis of the geomorphic indices is found very effective method for estimating the influence of relative tectonic activity. Geologically, the study area is dominated by sahyadri and satpuda group of rocks of late cretaceous - paleocene age. Structurally, this area is very complex with several lineaments and faults. River and tributaries of the area are irregular and mostly controlled by lineaments. On the basis of calculated RAT classes 17.98% (1879.05km^2) of the total area falls in class 3 indicates high tectonic activity in this region and 82.02% (8574.29km^2) falls in class 3 indicating moderate active tectonics. High values of HI and BS are probably due to uneven topography and presence of numerous lineaments and faults in the region. High values of SL index are may be due to lithological variations or due to recent tectonic activity. The result of this study confirms the calculation of different geomorphic indices and Relative active tectonic index (RAT) is very effective method for assessing tectonic activity.

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