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GIS Based Evaluation Of Relative Active Tectonics From Geomorphic Indices And Morphological Indices In Assam-Arakan Valley

Anjali Yadav[1*], Garima Aggarwal[2], Rajender Singh[3]

[1*]Department of Geography, Swami Shraddhanand College, University of Delhi
[2]Senior Consultant (RID), National Institute of Disaster Management, MHA, GoI
[3]Department of Geography, Shivaji College, University of Delhi

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Abstract

There are shelves, slopes, and basins in the sedimentary part of Assam-Arakan valley. The Dhansiri valley, which is situated among the Naga foothills and Mikir hills, and the Brahmaputra valley are both covered by the shelf portion of the basin. The shelf extends westward from the Digboi to the Shillong plateau's southern slope. Beneath the Naga schuppen belt is the hinge zone, or shelf-to-basinal slope. To estimate the relative index of active tectonics (RIAT) for the Assam region, many aspects of geomorphic analysis, such as hypsometric integral (HI), stream length (SL) gradient, basin form (BS), and valley floor (VF), have been utilized. When it comes to financial investments for hydrocarbon exploration from such terrains, tectonic (in)stability is a big worry. Landform deformation brought on by seismic frequency has a significant impact on the pattern of drainage basins and drainage anomalies, which in turn affect the pattern of distribution of floods. In order to classify the tectonic events that are leading to influences the geomorphic/morphometric indices and drainage pattern for the Assam valley are obtained. Such parameters can be estimated by using GIS based toolkits. The indices are categorized into three groups depending on tectonic activity (TA), and the relative active tectonics index (IRAT) is produced by averaging the classes. The four IRAT classes—extreme (1.57–1.80 as Class 1), high (1.81–2.06 as Class 2), moderate (2.07–2.26 as Class 3), and low (2.27–2.30 as Class 4)—are the ones that are defined for this research. The majority of the research area, according to the results, is located in extreme to moderately active tectonic regions, and these regions are congruent with large thrusts and faults that are exist in the basins. The identification of distorted landforms resultant from active tectonics is made possible by the integrated method of GIS-based geomorphic/morphometric assessment. The outcomes can also be used to create sustainable terrestrial usage development and watershed management.

Keywords: Active Tectonics, Geomorphology, Remote sensing, GIS, Assam-Arakan region, Drainage indices.

Terms Used:
AT: Active Tectonics
TA: Tectonic Activities
GIS: Geographic Information System
GSI: Geological Survey of India
IRAT: Index of relative active tectonics
RS: Remote Sensing
GI: Geographical Index

1. Overview

Located in northeastern India, the Assam-Arakan valley is classified as a category I basin. The basin is 116000 square kilometers in size. The Assam-Arakan Fold belt, Naga Schuppen belt, and Assam Shelf are the three main tectonic features of the basin. A region's tectonics, which can be determined by its fluvial, structural as well as morphotectonic features, is a major factor in the evolution of its drainage basins. Relative tectonics findings can be applied to the assessment of natural destructions like floods and earthquakes, as well as to the management/planning of sustainable land usage and land cover in seismically active areas. According to Mahmood and Gloaguen (2012), the research of ATs is multidisciplinary as well as significant from a socioeconomic standpoint. In a location as seismically active and prone to flooding as Assam, located in India's North Eastern Region (NER), assessing relative active tectonics is essential to understanding drainage patterns. Active processes such as faulting and folding greatly influence the drainage patterns of seismically active zones. The presence of dynamic processes results in changes to stream channel deflection, basin tilting, and morphological features (Cox, 1994). As a result, morphotectonic research serves as an instrument for identifying the zones where tectonic event has caused deformation (Keller and Pinter, 2002).

Fig. 1 Geographical map of Assam-Arakan Valley

The belt of Assam-Arakan fold-thrust, the Mishmi Hills, as well as the Arunachal Himalaya define the tectonic system of the Assam valley, which is the resultant of the Indo-Burmese and Himalaya-Tibet collisions as shown in Fig. 1. Numerous recorded earthquakes indicate that the region is seismically active. Based on the USGS statistics (https://earthquake.usgs.gov/ earthquakes), the region experienced 167 earthquakes with a magnitude of 2.5 between December 12, 1908, and November 22, 2020. The maximum compressive stress (SHmax) vectors of world stress map provide a sense of the plate movement in this section. The research area's NNW–SSE to NE–SW focused on SHmax vectors indicate that N–S compression is powering the Assam–Arakan and the Mishmi fold-thrust belt's frontal thrust sub-display systems.

The Himalayas, which climb from the N-E zone (India) to the west region of Hindu Kush (Afghanistan), are developed due to the contact among the Eurasian and Indian plates, which is what causes the great seismicity of the NER (Ghosh et al., 2018). The average rate of Indian plate convergence under the Eurasian Plate is 50 mm/year (Catherine, 2004) that creates the Himalayan belt as the world's most TA places. Because of the tectonic activity underlying it, the active tectonic zone experiences variations that might be rapid, fast, or slow. Folds, fractures, and basin formation are markers of previous tectonicactivity-induced deformation (Das et al., 2011). But the tectonic region's slow geomorphological variations can't be represented by easily noticeable changes in forms of basin drainage patterns or surface deformations (Agrawal et al., 2022). These silent changes can be detected in any place usinggeomorphic/morphotectonic assessment (Divyadarshini and Singh, 2019; Taesiri et al., 2020). Such variations in the river flow become an effective indicator of differential uplift caused by ATs because the drainage sequence is hypersensitive to TA as well as variations occur for various attributes of the drainage basins (Saber et al., 2020).

There were two significant tectonic development stages in the Assam-Arakan basin. It formed as a composite shelf-slope-basinal arrangement with a passive margin planning between the Early Cretaceous as well as the finishing of the Oligocene. However, throughout the post-Oligocene era, distinct evolutionary patterns were monitored in various regions of the megabasin, primarily due to compressive tectonic forces. In the southern slope of the Dhansiri valley and Shillong Plateau, several graben/horst structures formed on the granitic crust during the Middle to Late Cretaceous, when the Indian plate was migrating in north direction. These grabens are located on the southern slope of the Dhansiri valley as well as the Shillong

Plateau. The Khasi Group is responsible for a series of subordinate limestone, shales and sandstones towards the top that was deposited there, while the Dergaon Group is responsible for a sequence of sandstones and shale that was deposited there. The presence of pelagic animals suggests that such sediments were deposited between Early Paleocene and the Maestrichtian in shallow shelf to exposed aquatic environments.

Lower Disang shales, radiolarian cherts, and subordinate limestones were deposited during this time in the basinal area to the east and southeast in the distal deeper portion of a marginal downwarp, or slanted broad shelf next to the ocean basin. It's possible that the limestones with very little contaminants were deposited atop sea mounds. The Indo-Burmese trench zone has the deposition of upper Disang shales under deep marine situations. This trench system formed during the tilted subduction of the Indian plate beneath the Burmese region plate. It is possible that the trench system started to build in the northeast and moved slowly southward. Additionally, the trench system's closure began in the northeast and shifted gradually southward. The Indo-Burmese trench structure spreads into the Andaman trench (southward) that has been getting mainly argillaceous deposits subsequently likely the Upper Cretaceous-Paleocene.

A drainage basin's tectonic activity is mostly determined by the analysis of geomorphic indices and morphometric parameters (Ahmad et al., 2018). The hydrological/geomorphological/geological procedures of a basin can be identified with the use of morphometric parameters (Bahrami et al., 2020). According to Anand and Pradhan (2019), the process usually entails assessing the drainage basins' slope, stream gradient, linear, relief and areal. Drainage form factor, drainage texture, circulatory ratio, drainage stream frequency. Drainage texture/density, length ratio, bifurcation ratio, stream number/order, etc. are the primary morphometric parameter. The determination of morphometric parameters in drainage basins is crucial for managing floods and for building at the basin level. According to Selvakumar and Ramasamy (2014), drainage anomalies and topography changes significantly influence an area's flooding pattern. To comprehend how landforms react to bending procedures aa well as pinpoint the areas where TA is causing deformation, geomorphic indices are utilized. With the aid of GIs, the maturity of the evolved landscape in relation to the responsible deformation procedures can also be connected, and it may be classified and quantified based on its stages of erosion.

The research on AT (Taesiri et al., 2020) have successfully used GI like the HI (Strahler, 1952), symmetry of transverse topography (Cox, 1994), stream sinuosity (Mueller, 1968), stream length gradient index (Hack, 1973), the ratio of basin elongation (Bull and McFadden, 1977), asymmetric factor (Hare and Gardner, 1985) and the valley floor width to valley height ratio (Bull and McFadden, 1977). In order to distinguish between active zones, identify geomorphic anomalies connected to TA, and comprehend the evolution of landforms, GIs and morphometric parameters are thought to be defining instruments (Keller and Pinter, 2002). For morphometric and geomorphic investigations, remote sensing and GIS are crucial for data collection and spatial analysis. This strategy saves time as well as removes the possibility of errors that could occur when collecting data using traditional techniques.

Other active tectonic regions like the Indian state of Nagaland, the Afghan Hindu Kush region, the Siwalik Hills of the Northwest and Northeast Himalaya, the Qianhe river basin in North China, the Greater Antilles in North America, the Mediterranean Sea coasts of Spain, and northwest Iran have all seen success with similar approaches. The current study evaluated the progressive variations in the basin zone caused by ATs by extracting GIs and morphometric attributes from the Assamese digital elevation model (DEM) as well as quantitatively analyzing them. The Himalayan foreland's morphology has been impacted by the ongoing tectonic movement (Biswas and Paul, 2021). Thus, employing a GIS-based methodology with remote sensing data, an effort was done to assess the TA of the whole Assam state depending on GIs and morphometric features.

2. Regional Setting

This fold belt can be split into two zones, separated by prominent thrusts: (i) the central flysch zone i.e. located among the Tapu as well as Changrang – Zunki thrusts and has exposures primarily of Disang shales; (ii) the Naga fold zone, which is located between the Disang and Tapu thrusts and has exposures of Disang shales and Barail sediments. To the north of Assam are the Main Boundary Thrust (MBT) and Main Frontal Thrust (MFT), which stretch from west to east; to the south of the Brahmaputra Basin is the Shillong Plateau, which is made up of the Mikir, Shillong and Naga Hills (Fig. 2) (Das, 2004). The Himalayan-Mishmi-Naga Patkai Thrust structure caused tectonic compression in the Upper Assam area. The Mikir hills are located to the Upper Assam of southwest zone, the Naga-Patkai hills to the SE, and the Mishmi hills to the NE. The Shillong plateau and Mikir massif in the Assam region are divided by the NW-SE trending Kopili Fault and the alluvial sediment of the Kopili River. The oldest Archaean-Proterozoic gneiss and schist rocks, including as quartzite, phyllite, and amphibolite, are found in the Mikir Hills. These rocks are unconformably covered in Proterozoic Shillong Group rocks. The main water split among the Barak valleys and Brahamputra in the Barail mountain range. It comprises of a rock group from the Oligocene era that reaches the optimum thickness of 1,000 meters in the North Cachar Hills. It encompasses the North Cachar Hilly zone.

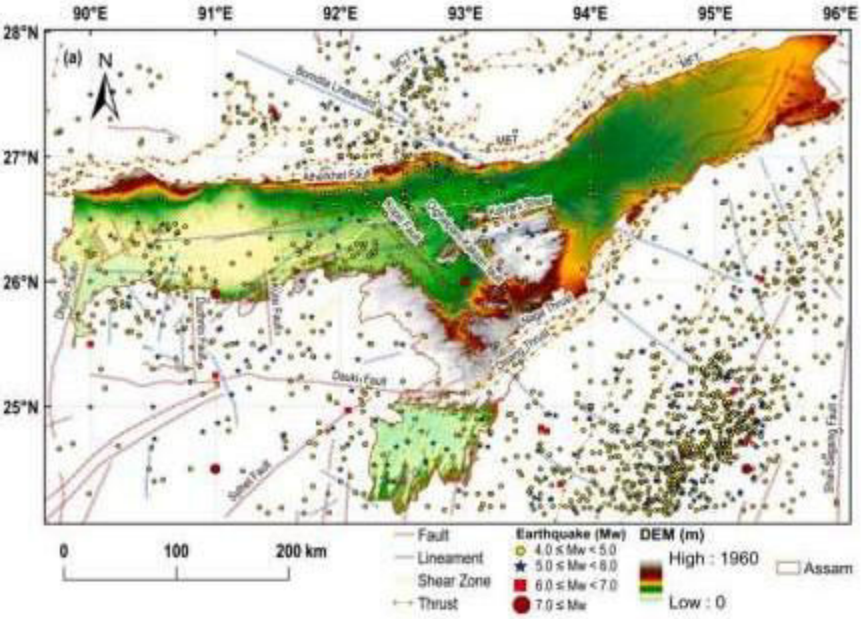

Fig. 2 Map of major tectonic regions of Assam with elevation and seismicity (Gupta, Agrawal, Dixit, & Dutta, 2022).

With its intricate tectonic and geological surroundings, Assam is located in the northeastern Himalayan foothills. The Brahmaputra River system i.e. heavily braided, multichannel, as well as governed by tectonic activity and geotectonic configuration, dominates the Assamese flood plains (Gupta and Dixit, 2022a). The region is prone to disastrous floods every year because of the extensively the extreme monsoon duration and braided Brahmaputra River. Because of the activity of prominent tectonic features, this region has already seen a number of large earthquakes, up to Mw 8. The state of Assam's primary industry is agriculture, and the zone is extremely abundant in fauna/flora. The region's social, economic, and environmental environments are at risk from a variety of man-made and natural hazards, such as seismic events.

Fig. 3. Research regions of the upper part of Assam valley including the earthquakes that happened in the region among the years 1908-2020. (Gogoi, Gogoi, & Mukherjee, 2022)

3. Methodology

To evaluate the TA of the Assam zone, the current research attempts to determine GI as well as morphometric parameters using a Geographic Information System (GIS). The Brahmaputra and Barak valleys make up the research region, which is further subdivided into 10 basins with stream orders ranging from first to seventh order (Strahler, 1952). In the current work, morphometric characteristics as well as GIs are assumed to be quantifiable for basins with stream orders equal to or greater than 3. Due to the aid of 1 arc second Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM) dataset with a resolution of 30 meters, the MPs (lines and areals) and GIs are retrieved (https://earthexplorer.usgs.gov/). With an absolute horizontal precision of ± 8.8 m as well as a vertical accuracy of ± 6.2 m (with 90% confidence), the SRTM is depending on C-band radar interferometry data and has a greater accuracy of roughly ± 16 m (RMSE of 9.73 m) globally. Datasets involve the seismotectonic characteristics (such as thrusts, shear zones, lineaments and faults) of the research domain are achieved from Bhukosh (Bhukosh-GSI). Data regarding the date of occurrence and magnitude of earthquakes are assembled from various resources, such as National Center for Seismology, Bhukosh-GSI, International Seismological Centre and US Geological Survey, (Gupta et al., 2021).

To comprehend geomorphology, tectonics, and structural research, GIS and RS are utilized. Utilizing SRTM DEM (30 m) (https:// earthexplorer.usgs.gov/) and SOI toposheet numbers 46H/ 4 as well as 46D/ 16 (1:50,000) in a GIS context, the stream network and the watershed borders were drawn. On a GIS platform, image processing, the linear feature recognition, creation of the incorrect color composite picture, and compilation of the shaded relief maps were carried out. Using DEM and Google Earth data, the GIs (BS, VF, HI and SL) were computed using the following formulas (Table 1). The Indian plate's interior is made up of a complex lithological framework and tectonics that have evolved over a lengthy geological period. The construction as well as alteration of these structures are significantly affected by ATs. The MIs, VF, BS, HI and SL, are now known to be continually applied so as to compute the RIAT. The sub-watersheds were divided into three classes according to the index value after the entire indices were evaluated. To categorize each sub-watershed depending on the RIAT, all of the indices were added together and separated into the desired indices number. The outcome was supported by field data, fault/lineament-map and stream deflection parameters.

4. Assessment of indices

The instruments that aid in identifying deformational processes and the evolution of a landform as a result of dynamic processes are morphometric parameters and geomorphic indices (Bhat et al., 2020). Such indices distinguish between the tectonically active zones of the area by acting as indicators of drainage system anomalies brought on by tectonic activity. Ten basins were identified in the current study, and each basin's GIs and MPs were assessed. Based on the range of results for each index, three tectonic classes were identified. Table 1 and table 2 display a schematic illustration of the geomorphic index parameters. In last, the arithmetic mean of the GI classes and MP values was used to compute the IRAT, which was then divided into four TA classes for the whole zone.

Table 1 Mathematical expressions and explanation of MPs along with the categorization of the entire attributes into various classes

Category	Indices	Expression	Parameters		Range	Class
Linear	Bifurcation ratio (Br)	$B_r = \frac{N_u}{N_{u+1}}$	Nu is the stream number of a definite order, Nu+1 is the higher-order streams number		Between 1.25 (Basin 7) and 3.58 (Basin 5)	13.58–2.32; Class 1, 2.31–2.00; Class 2, and <2.00; Class 3
	Stream length ratio (Lr)	$L_r = \frac{L_u}{L_{u-1}}$	Lu is the definite stream order's total length, and Lu-1 is the lower order total stream length		Maximum is 2.14 (Basin 5) and Minimum is 0.48 (Basin 8)	2.14–1.11; Class 1, 1.12–0.55; Class 2, and <0.55; Class 3
Areal parameters	Drainage density (Dd)	$D_d = \frac{\sum L_t}{A}$	A is the total area of basin and Lt denotes the total stream length		Maximum is 0.23 (Basin 1) Minimum is 0.19 (Basin 10)	0.23–0.208; Class 1, 0.207–0.20; Class 2 and <0.200; Class 3
	Drainage stream frequency (Fs)	$F_s = \frac{\sum N_u}{A}$	A refers the total area of basin and Nu is the total stream segments in basin of the entire orders		Basin 3 (0.131)- Basin 10 (0.169)	0.169–0.145; Class 1, 0.144–0.140; Class 2, and < 0.140; Class 3
	Drainage texture (Dt)	$D_t = \frac{\sum N_u}{P}$	P is the perimeter of basin and Nu is the total stream segments in basin of the entire orders		Basin 4 (0.354)- Basin 6 (2.638)	2.638–2.109; Class 1, 2.108–0.536; Class 2, and <0.536; Class 3

	Circularity ratio (CR)	$CR = \frac{4\pi A}{P^2}$	P and A refer the basin's perimeter and area, respectively.		Basin 4 (0.122) - Basin 10 (0.301)	0.122–0.207; Class 1, 0.208–0.264; Class 2, and 0.265–0.301; Class 3
	Form factor (Ff)	$Ff = \frac{A}{L_b^2}$	Lb refers the length of basin and A signifies the area of basin		Basin 2 (0.178) - Basin 8 (0.364)	0.178–0.207; Class 1, 0.208–0.330; Class 2, and >0.330; Class 3

Table 2 Mathematical expressions and explanation of GIs with the categorization of the entire attributes into various classes

Indices	Expression	Parameters	Range	Class
Stream-length gradient index (Sl)	$Sl = (\frac{\Delta H}{\Delta L_r}) * L_t$	Lt is the horizontal distance from the separation of the watershed reach midpoint, △Lr is the length of the reach, and △H is the change in elevation level	Basin 4 (62.58) – Basin 9 (466.87)	>250; Class 1, 250–120; Class 2 and <120; Class 3
Valley floor width to valley height ratio (Vfh)	$Vfh = \frac{2Vf_w}{(E_{rd} - E_{sc}) + (E_{ld} - E_{sc})}$	Esc is the average elevation of the valley floor, Vfw is the width of valley floor, and Eld and Erd are the elevations of the left and right valley separate facing towards downstream direction	Basin 7 (0.260) – Basin 1 (8.540)	0.260–0.660; Class 1, 0.661–0.900; Class 2, and (>0.900; Class 3
Hypsometric integral (Hi) and hypsometric curve	$H_i = \frac{(Elev_{mean} - Elev_{min})}{(Elev_{max} - Elev_{min})}$	Elevmax, Elevmin and Elevmean are the maximum, minimum and mean elevation of basin	Basin 9 (0.020) – Basin 4 (0.287)	0.200–0.287; Class 1, 0.100–0.199; Class 2, and <0.100; Class 3
Asymmetric factor (Af)	$A_f = (\frac{A_r}{A_t}) * 100$	At refers the total basin's area and Ar refers the area of basin to the right of the mainstream towards downstream direction	Basin 5 (0.144) - Basin 3 (26.678)	17.831–26.678; Class 1, 8.981–17.830; Class 2, and <8.981; Class 3
Drainage basin shape index (Bs)	$B_s = \frac{B_l}{B_w}$	Bw is the maximum measured basin's width and Bl refers the total distance calculated from the basin's source to the mouth	Basin 5 (0.080) - Basin 3 (0.540)	2.450–3.080; Class 1, 1.830–2.449; Class 2, and <1.830; Class 3
Basin elongation ratio (BE)	$BE = \frac{2(A/\pi)^{0.5}}{B_l}$	Bl and A are the basin's maximum length and area	Maximum is 0.684 Minimum value is 0.477	0.477–0.502; Class 1, 0.503–0.664; Class 2, and 0.665–0.684; Class 3
Stream sinuosity (SS)	$SS = \frac{CL}{L}$	L refers the straight line joining the two ends of the channel and CL represents the stream channel's length	Maximum is 2.102 (Basin 9) Minimum value is 1.114 (Basin 10)	1.114–1.171; Class 1, 1.172–1.450; Class 2, and 1.451–2.102; Class 3
Indices of relative active tectonics (IRAT)	$IRAT$ $\_\ (Avg\ Geo + Avg\ Ln + Avg\ Al)/$	n refers the parameter numbers and Avg Al, Avg Ln and Avg Geo are	Minimum value is 1.57 (Basin 1) Maximum	1.57–1.80; Class 1, 1.81–2.06; Class 2 and 2.07–2.26; Class 3 and (2.27–2.30);

		average values of areal, linear and GIs parameters class, respectively	is 2.30 (Basin 3 and 10)	Class 4

The outcomes of GIs and MIs of the ten basins are provided in Table 3 and Table 4, respectively.

Table 3 GIs parameters.

Basin no	**Sl**	**Vfh**	**Hi**	**Af**	**BS**	**T**	**BE**	**SS**
1	269.83	7.98	0.08	18.89	2.97	0.39	0.53	1.14
2	120.08	0.88	0.23	16.29	1.65	0.42	0.51	1.25
3	123.28	1.09	0.09	25.99	1.54	0.49	0.65	1.38
4	59.98	0.65	0.31	13.87	1.43	0.26	0.64	1.07
5	84.23	0.85	0.14	0.18	1.61	0.11	0.71	1.51
6	189.73	1.72	0.11	11.79	2.44	0.39	0.45	1.15
7	169.79	0.34	0.18	3.38	2.72	0.28	0.61	1.28
8	613.34	4.89	0.18	9.97	1.19	0.30	0.73	1.88
9	455.79	1.39	0.00	15.98	1.99	0.21	0.59	2.09
10	187.42	0.59	0.05	13.02	2.18	0.29	0.72	1.07

Table 4 Mis parameters

Basin no	Linear Parameters			Areal Parameters					
	Br	Lr	Avg Ln	Fs	Dd	Dt	CR	Ff	Avg Al
1	1.75	1.75	1.75	1.75	0.75	0.75	0.80	0.80	1.26
2	3	1.75	2.5	3	0.75	3	1	1	2
3	1.75	3	2.5	3	0.75	2.75	2.25	2.75	2.34
4	3	1	2	2	2	3	0.80	2	1.97
5	0.75	0.75	0.75	1.75	2	2	2.75	3	1.71
6	1.75	3	2.5	2	0.75	0.80	0.80	0.80	1.55
7	3	2	2.5	0.75	2.5	3	2.5	2	2.28
8	0.75	3	2	1.75	3	2	2	3.25	2.21
9	0.75	3	2	2	3	1.75	2.25	2.25	2.12
10	3	1.75	3	0.75	3	2	3	3	2.43

Lastly, the values achieved for IRAT were further categorized into four classes as Class 1, Class 2, Class 3, and Class 4, referring the extreme, high, moderate, and low TA, respectively. Basin 1 has the lowest IRAT value of 1.57, while basins 3 and 10 have the highest value of 2.30. The study yielded four grades for IRAT: 1.57–1.80; Class 1 denoting extreme TA, 1.81–2.06; Class 2 denoting high activity, 2.07–2.26; Class 3 denoting moderate activity, and 2.27–2.30; Class 4 denoting low activity. Class I includes Basins 1 and 6, which together occupy an area of roughly 47,740 km2. Basins 2, 4, and 5 have a total area of 2507 km2, whereas basins 7, 8, and 9 are under Class 3 and have a total size of 17,495 km2. Class 4 is made up of basins 3 and 10, which have a total area of 2,090 km2.

5. Results & Discussion

The principal faults along which the IRAT's Class 1 (Basins 1 and 6) and Class 2 (Basins 2, 4, and 5) are located in this study are the Kopili, Dhubri, Kalyani, principal Frontal, Dudhnoi faults, Bombdila Lineament and Main Boundary. The basins belonging to such two IRAT classes exhibit high to moderate hypsometric integral, stream sinuosity, stream length gradients, asymmetric valleys, extended basins and divergence of streams from the basin midline, all indicative of neotectonic processes. The majority of the basins in classes 1 and 2 are U-shaped valleys with moderate to low indexes of valley floor width to height ratio. Low to moderate IRAT values are observed in central Assam and the Barak valley, whereas very high to high IRAT values are found along the mountain front that runs from W-E of the research domain. It also demonstrates how the region's diverse tectonic and geological settings cause the tectonic activity to be unevenly distributed.

Fig. 4 The road and rivers sections involve the tilted terraces in Assam Valley

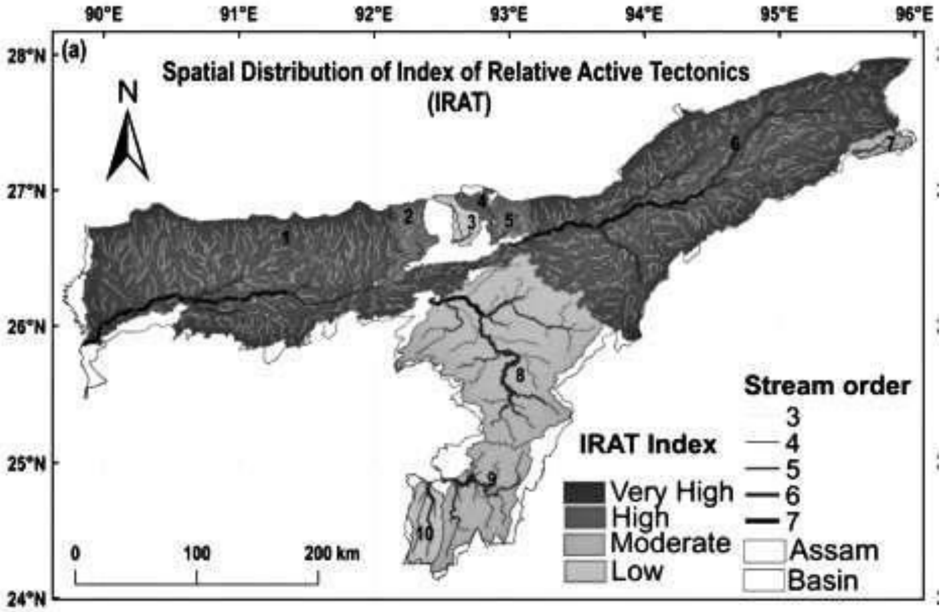

Fig. 5 Spatial distribution of IRAT in Assam with tectonics intensity

Important thrusts, lineaments and faults, like the Kalyani Shear Zone, Kopili Fault, Dhubri Fault, etc., are characteristics of the Assam region. The Assam zone's tectonic activity is influenced by these seismotectonic factors. The magnitude-per-unit area is mostly computed by line density using polyline characteristics within a radius of each cell. In comparison to neighboring areas, the topography of the high fault density zones is smoother and the basin is more tilted. These zones have a high number of fractured zones as a result of erosional processes. It is discovered that the IRAT distribution map and the area of basins 1, 2, 4, 5, and 6 exhibit strong correlations with high fault densities.

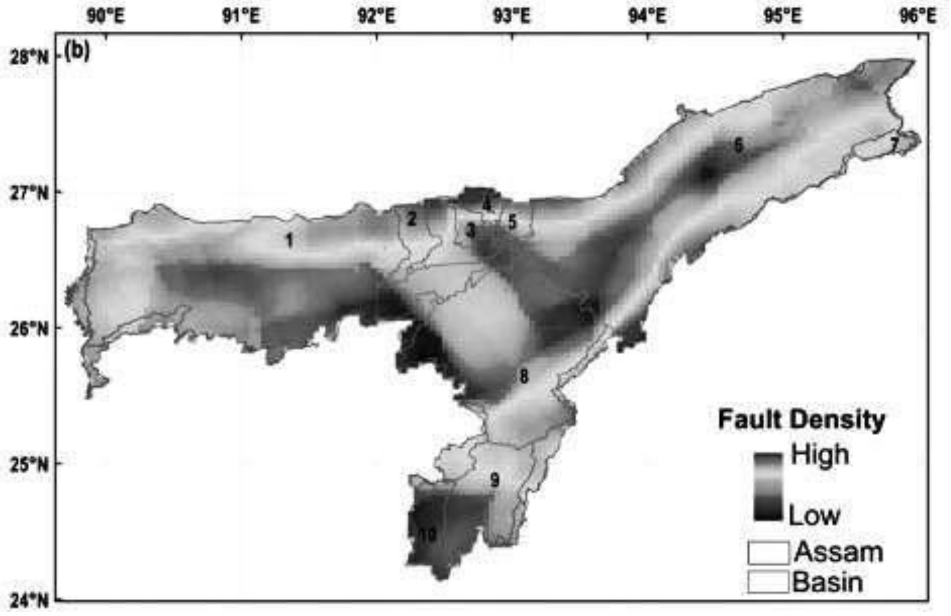

Fig. 6 Spatial distribution of Fault Density in Assam with tectonics intensity

The Sl index as well as longitudinal profile values both indicate an increasing trend in the vicinity of the tectonically active zones. In the ten basins under investigation, the values of the stream-length For each of the ten basins, areal and linear parameters are assessed in this study. After determining the basin's stream order, it is discovered that the ten basins range in order from the third to the seventh (Strahler, 1952). The segment number reduces as the order of streams up surges; for instance, a seventh order stream will have fewer segments than a sixth order stream. Lower order streams indicate how highly divided the basin area is. The Bifurcation Ratio (Br) is larger in the basins 1, 3, 5, 6, 8, and 9, where significant faults such as the Dhubri, Dhansiri Kopili, Kalyani, Dudhnoi, Bombdila Lineament, Naga, Main Boundary and Main Frontal passes through.

gradient (Sl) index are quantified. The majority of the basin area is found to be in the high to moderate ranges; specifically, 39,525 km2 is classified as Class 1: high and 27,801 km2 as Class 2: moderate. A basin's tectonic or erosional processes can be identified by looking at the proportion of valley floor width to valley height (Vfh). A lower value of Vfh indicates the dominance of TA over the erosional procedure. It is discovered that basin 7 has the least value of Vfh, 0.26, and basin 1 has the largest value, 8.54. This suggests that basins 7 and 1 are formed like V- and U-shaped valleys, respectively. The Vfh value is lesser than 1, for basins 2, 4, 5, 7, and 10, signifying a valley in the shape of a V and a juvenile stage of basin development. Basins 1, 3, 6, 8, and 9 have Vfh values greater than 1, which indicates that depositional/erosional procedures predominate as well as cause the formation of broad U-shaped valleys. El Hamdouni et al. (2008) state that the hypsometric curve illustrates a basin's developmental stages, and the Hi calculates the entire non-eroded basin's volume. Comparable to the Sl index, the hypsometric integral is unrelated to the RIATs. Elevated Hi values suggest that the terrain has changed as an outcome of current incision into new geomorphic surfaces created by depositional processes or active tectonics. The current research computed Hi values are comparatively low, fluctuating from 0.002 to 0.287. To calculate the tilt of a basin caused by tectonic activity, the Af of all 10 basins is computed. The existence of ATs will cause the basin to tilt when the value of Af is larger than or less than 50. If the value of Af is nearly 50, there won't be any tilting (Ahmad et al., 2018). Basins 1 and 3 in the current research are part of Class 1 (19.15–26.68), which spans 23,293 km2 as well as is known as a extremely tectonic zone because it contains several significant faults and thrusts, including the Main Frontal Thrust, Kopili Fault, Dhubri Fault, Dudhnoi Fault and Main Boundary Thrust.

A basin's shape is mostly determined by its tectonic activity or topographic evolution; so, the basin shape index is computed to determine the tectonic activity of the basin. In general, places with active plate tectonics tend to have longer basins, while regions with less or no plate tectonic activity tend to have circular basins. The study's findings demonstrate a significant relationship between tectonic elements including thrust, faults, and lineaments and the basin's structure. The basin elongations, which span 48,347 km2, are located in basins 1, 6, and 7. They are classified as 2.45–3.08; Class 1, or substantial TA.

Table 5 Data Analysis for the calculation of Hypsometry Curve for Assam-Arakan Valley

Relative Elevation (h/H)	Relative Area (a/A)									
	Basin 1	**Basin 2**	**Basin 3**	**Basin 4**	**Basin 5**	**Basin 6**	**Basin 7**	**Basin 8**	**Basin 9**	**Basin 10**
1	0	0	0	0	0	0	0	0	0	0
0.9342	0.2275	0.4386	0.4837	0.3125	0.2563	0.3178	0.4628	0.5189	0.4986	0.3986
0.8812	0.4466	0.4899	0.5162	0.3942	0.3874	0.4103	0.5167	0.5793	0.5189	0.4189
0.8241	0.5722	0.6748	0.5627	0.4628	0.4539	0.4983	0.5946	0.6145	0.5391	0.4819
0.7713	0.7442	0.729	0.5941	0.4928	0.4902	0.6571	0.6284	0.6469	0.6189	0.5275
0.7142	0.8432	0.7991	0.6237	0.5183	0.5142	0.7189	0.6793	0.7105	0.6428	0.5837
0.6812	0.9187	0.8546	0.6825	0.5747	0.5792	0.7837	0.7463	0.7447	0.6839	0.6189
0.6245	0.9672	0.9019	0.7256	0.6232	0.6173	0.8263	0.7779	0.8056	0.7848	0.6584
0.5513	0.9618	0.9182	0.7772	0.7594	0.7037	0.8731	0.8349	0.8479	0.8139	0.7029
0.5144	0.9667	0.9562	0.8538	0.7943	0.9098	0.8915	0.8772	0.8839	0.8785	0.7434
0.4413	0.9715	0.9676	0.8946	0.8493	0.9278	0.9012	0.9018	0.9005	0.9196	0.8146
0.3845	0.9763	0.9782	0.9016	0.8766	0.9322	0.9256	0.9273	0.9276	0.9472	0.8793
0.2746	0.9813	0.9892	0.9262	0.8946	0.9809	0.9389	0.9489	0.9902	0.9842	0.9142
0.2207	0.9826	0.9901	0.9485	0.9927	0.9845	0.9746	0.9794	0.9926	0.9901	0.9487
0.1647	0.9956	0.995	0.9847	0.9975	0.9892	0.9896	0.9847	0.9945	0.9954	0.9919
0.1304	0.9968	0.9961	0.9918	0.9984	0.9917	0.9935	0.9902	0.9989	0.9982	0.9973
0.0548	0.9998	0.9982	0.9951	0.9998	0.9967	0.9996	0.9992	0.9995	0.9996	0.9999
0	1	1	1	1	1	1	1	1	1	1

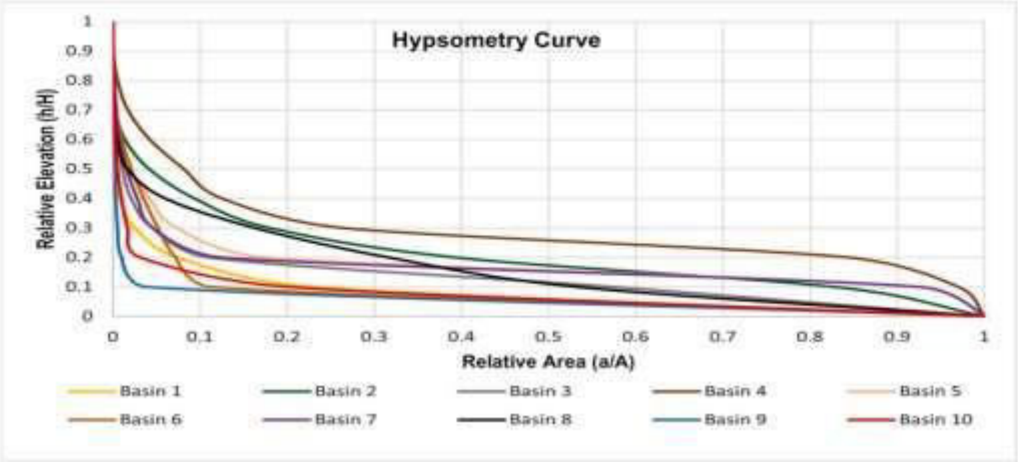

Fig. 7 Hypsometry Curve for the ten Basins in Assam-Arakan Valley

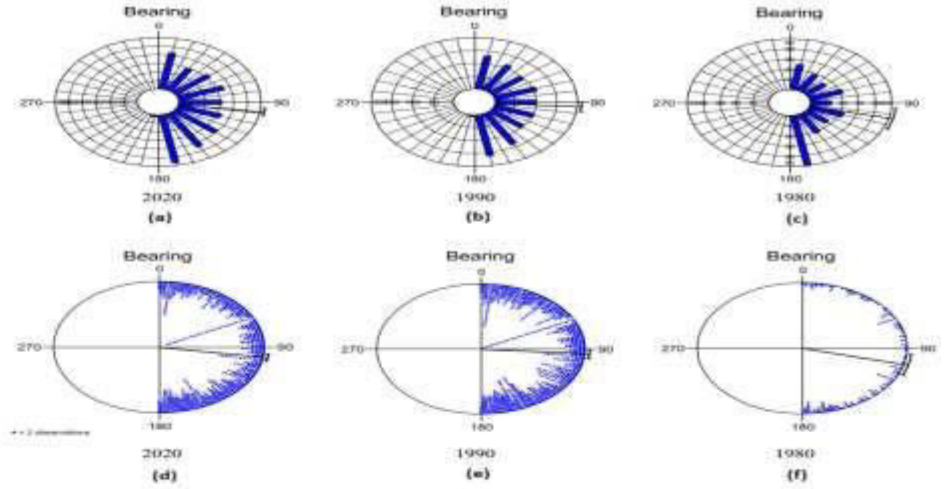

Fig. 8. The orientation change, lineament overlay and lineament distribution assessment from 1980 to 2020: (a) Circular histograms (2020), (b) Circular histograms (1990), (c) Circular histograms (1980), (d) Circular arrow data plots (2020), (e) Circular arrow data plots (1990), (f) Circular arrow data plots (1980)

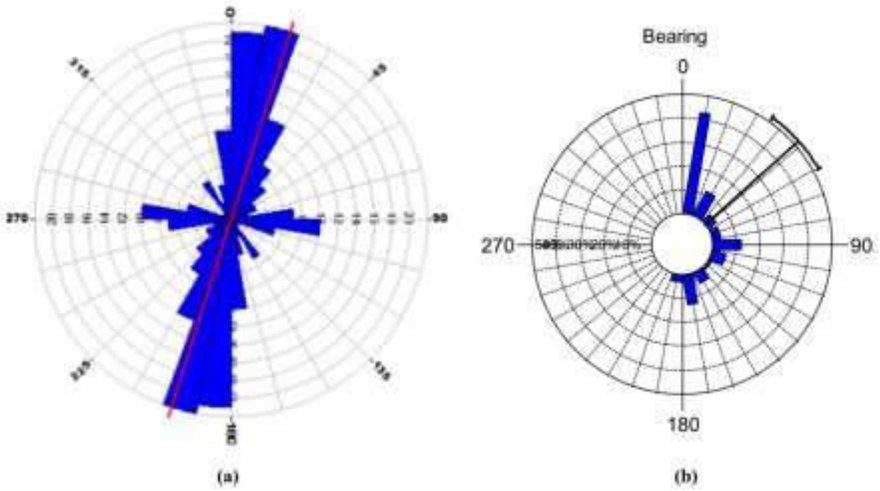

Fig. 9. The representation of major faults distributions by rose diagrams and circular histogram in Sylhet City and nearby regions. (a) Rose maps and (b) circular histogram.

The temporal lineament distribution and rose diagrams show that the estimated lineaments trends are NE–SW, or somewhat parallel to the Schuppen belt Fault in Burhi Dihing, and E–W, or parallel to the Tingabai Fault. The vector line in both forms of circular maps—circular histograms as well as circular arrow data plots—refers the mean direction/angle, and the segment external the circle shows that the 95% confidence interval has altered throughout a 40-year cycle.

6. Conclusions

An improved comprehension of the previous tectonic disturbances that took place in a location can be attained by utilizing morphometric factors in conjunction with geomorphic indices. It serves as a reconnaissance tool to evaluate drainage anomalies and distinguish between active tectonic zones. In an area like Assam that is prone to earthquakes and floods, where the course and shape of the river basin have changed over time, this approach becomes crucial for managing water resources and land use in a sustainable manner. In addition to the scant data representing the zone's TA, the geomorphic evidence confirms and quantifies the level of TA. The area features quite variable precipitation range (2700–4300 mm annually), a lithology that is prone to erosion, and a humid weather. It could be the cause of certain indicators indicating a lower tectonic activity in the region. Erosion is exacerbated by these lithology and climate factors. The results may be impacted to some extent by the higher erosion rate erasing tectonic activity evidence. TA assessment using GI analysis, including IRAT, Vf, SL, Bs, T, Af, Smf and Mountain front steepness (S), is part of the current study. The zone is TA, based out the indices Af, T, SL, and S. Tectonic activity is indicated by multiple levels of paired, unpaired, tilted, horizontal terrace deposits.

Moreover, strath terraces and minor faulting in the terrace sediments are indications of continuous tectonic activity. Thus, we might draw the conclusion that tectonic deformation has recently occurred in the area. However, results from the parameters Bs, Vf and Smf, show that the zone is either moderately or less active. In this study, the IRAT assessment takes into account all other factors and is computed independently for Vf obtained at two distinct transect distances: 300 m and 1 km. The region is classified as having lower TA (class 4) based on the Irat data. Additionally, we compute Irat using the attributes (Af and SL) that indicate strong TA; the outcome indicates that the region is active (class 2). According to several indexes, the area is not as active. The reason for this is that we are adhering to the index range that is determined by our research in dry as well as semi-arid climates. The range needs to change for the area with tropical to subtropical weather as well as a crumbly sedimentary rock type. The region's heavy rainfall erodes the mountain faces, widening valleys where there is less rock resistance. Therefore, changes in valley forms and mountain front sinuosity, which impact changes in the current morphological features of the region, are not solely instigated by TA.

The Assam valley is a tectonically active area due to its typical seismic setting. Frequent earthquakes caused by neotectonics along the closly fault systems can endanger the lives of people living in small township regions like Doom Dooma, Dibrugarh and Tinsukia. They can also lead to the failure of large-scale engineering projects like bridges and dams, and most concerningly, different oil/coal-Beld constructions. Fluvial characteristics are most susceptible to the effects of lithospheric tectonics and endogenic dynamics, which produce surface characteristics. The information provided by this study points to neotectonic shifts that have affected the fluvial systems during the past few decades. Identification and morphometric examination of these fluvial alterations can yield proof of neotectonic activity stemming from plate movements and enhance comprehension of potential future additions or modifications to the system. To summarize, the next line of inquiry for these investigations will be predictive geomorphic models of the terrain.

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