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ASSESSMENT OF LANDSCAPE EVOLUTION AND SPATIO-TEMPORAL VARIATIONS IN TECTONIC PULSES IN THE VAIGAI RIVER BASIN, SOUTHERN INDIA

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ABSTRACT

Earth's surface processes are active at variable scales resulting in spatial variations in topography that evolve under the primary controls of tectonics and climate, among others. On a river basin scale, these differences could be gauged through systematic documentation and analysis of morphometric metrics. The modern Vaigai River Basin is located in an antecedent valley or basin that owes its configuration and morphology to Precambrian-Recent tectonic-climatic-land use dynamics. This complexity and continuum of evolutionary history have hampered systematic documentation and comprehension of its evolution. We have investigated and studied the geomorphic aspects of this river with the help of ArcGIS 10.5 to understand the rock uplift, river incision and tectonics in the Vaigai River Basin by examining the longitudinal profiles, Asymmetric factor (Af), Transverse topographic symmetry factor (T). Thematic maps of geology and geomorphology were extracted from the Bhukosh website data and created. Vaigai River and its tributaries display uneven longitudinal profiles with numerous knick points along the profiles. Major breaks are observed only in the main channel where the river starts. River incision is not uniform in the Vaigai River. The streams become graded (absence of knickpoints) towards the river mouth, suggesting that the uplift and incision are in equilibrium. The Vaigai is highly elongated and it is easier to control floods in this basin. Upstream of Vaigai River and its tributaries have shown that a series of breaks and knickzones indicate active erosion and acute lithological control on the channel. The Asymmetry factor (Af) and the Transverse topographic symmetry factor (T) emphasize the tectonic control. Different lithological stages on knickpoint and channel incision substantiate the rejuvenation of Vaigai River in several phases during the geological past.

Key Words: Longitudinal profiles; Knickzones; Lithology; Tectonics

1. INTRODUCTION

The river's course, channel geometry, and river valleys can all be affected by the rise and fall of the river's base profile which could be caused by tectonics or climate change. The rivers in India are typically divided into those that flow west and those that flow east. Several examples include the Narmada, Tapti, Sharavathi, Kali, Nethravathi, and

Periyar rivers, which flow westward and have the Western Ghats as their source. The Mahanadi, Godavari, Krishna, Cauvery, Damodar, Brhamani, Palar, Pennar, Vaigai, and Thamirabarani are significant rivers that flow east in Southern India. The east-flowing rivers are mostly affected by tectonics, climate change, and the Indian plate movement, whereas climate change primarily controls the west-flowing rivers (Kale and Rajaguru, 1988). Endogenic and exogenic processes operate as highly coupled systems, indicating tectonic and climate feedback, particularly in active mountain ranges along convergent margins (Roe et al., 2008). However, in a natural landscape, the feedback of ridgelines and subsequent rain-shadowed topography is less understood. The longitudinal profile development also depends on the variability of lithology (Stock and Montgomery, 1999; Duvall et al., 2004), and river longitudinal profiles exhibit tectonic activity through their overall morphology and knickpoints in areas where the gradient of the river changes quickly.

The main goal of this research is to find out how rivers react to changes in the stability of the land and how the profiles of the Vaigai River and its tributaries have changed over time, utilizing quantitative analysis of longitudinal profiles. Additionally, this study aims to understand whether the knickpoints in the Vaigai River basin are controlled by lithology or by base-level changes resulting from active tectonism. To examine the control of tectonism, various metrics- the asymmetry factor, Transverse topographic symmetry factor (T), Circularity ratio (CR), Basin Elongation ratio (BE), and River Sinuosity (SS)- have also been used.

2. REGIONAL SETTING

The Vaigai River Basin, covering an area of 7380.60 Sq.km, is located in the Tamil Nadu state, encompassing five major districts: Theni, Dindigul, Madurai, Sivagangai, and Ramanathapuram. It is situated in the southern part of India, where the Western Ghats serve as the source of many east-flowing rivers. The basin (Figure 1) has an arcuate shape, stretching from the Western Ghats mountain range of Kerala in the west to the Bay of Bengal in the east, with a general gradient towards the northeast, up to Theni, and then in a south-eastern direction toward the sea. The river basin is bordered by the Western Ghats on the south and west, the southern slope of Palani hills (Kodaikanal hills), Sirumalai hills, Alagar hills, etc., on the north, and the Bay of Bengal on the east. Water is supplied to the Vaigai River's left bank via the large tributaries Suruliar and Manjalar. The Vaigai River is one of the east-flowing rivers originating from the Western Ghat in Varasanadu hill. Southern India is surrounded by the Indian Ocean, where all the east-flowing rivers drain into the Bay of Bengal (BOB), and the West-flowing Rivers drain into the Arabian Sea. The study by Richards et al. (2016) espoused that the evolution of the Western Ghats was attendant to the collision of the Indian Plate during the Early Cenozoic. The topographic rise commenced from the south and proceeded to the north, while an intensive tilt toward the east commenced around 25 Ma, continuing until today at a rate of 0.1 mm/year.

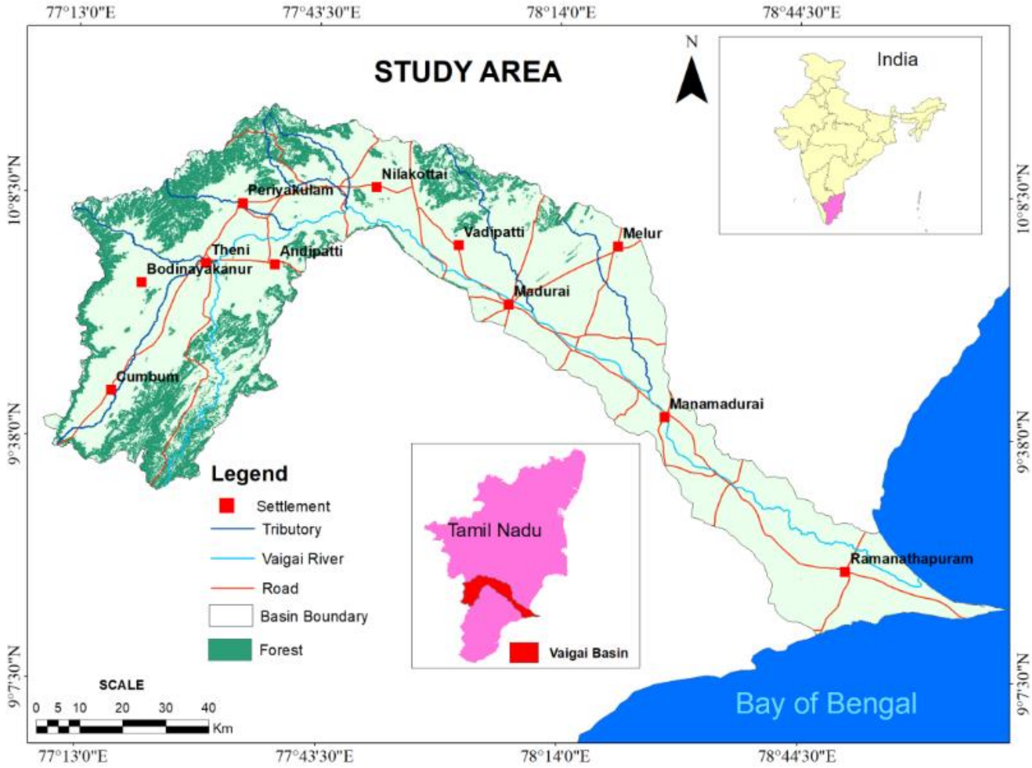

Figure 1. Study area

The edge of the Western Ghats currently forms the main drainage divide of Peninsular India. Archean greenstone belt, charnockite, felsic orthogenesis, granite, khondalite, migmatite, and sedimentary cover are found in the peninsular region. The east coast of South India is draped with a sedimentary cover, and the drainage owes its origin to the Western Ghats, which drains the eastern part of the South Indian Plate with larger basins. The Vaigai river basin is covered by hard crystalline rock masses of Archaean age on the western portion, mostly covered with charnockite, migmatite, and gneiss (see Figure 2). Additionally, Archean greenstone belts, charnockite, felsic orthogneiss, granite, khondalite, migmatite, and sedimentary cover are found in the peninsular region, as reported by Ramkumar et al. (2019). From Manamadurai to the Bay of Bengal, rocks of upper Gondwana, tertiary alluvium, and coastal alluvium unconformably overlay the Archaean formations. Highland charnockite massifs make up the Southern Granulite Terrane (SGT), which is divided into three sections by a network of low-lying shear zones extending in different directions: NE-SW, E-W, and NW-SE (Mukhopadhyay, 1986). Vaigai River has a minor delta even though it is a perennial river originating from the Western Ghats. The selected major river Vaigai, which flows easterly and south-easterly, has deltaic platforms in its mouth (Ramkumar et al., 2016). Delta head starts from Manamadurai at 77 m above sea level. 270 km major drainage system along with other important tributaries:

Sirumalaiyar, Manjalar, Varahanadhi, Theniar, Varattar-Nagalar, Suruliar, Sathiyar and Uppar. (Alternative-From Manamadurai to the Bay of Bengal, rocks of upper Gondwana, tertiary alluvium, and coastal alluvium unconformably overlay the Archaean formations. The Southern Granulite Terrane (SGT) is primarily composed of highland charnockite massifs, divided into three sections by a network of low-lying shear zones extending in different directions: NE-SW, E-W, and NW-SE (Mukhopadhyay, 1986). Despite being perennial rivers originating from the Western Ghats, the Vaigai River and other selected major rivers have minor deltas at their mouths (Ramkumar et al., 2016). The delta head starts from Manamadurai at an elevation of 77m above sea level. The Vaigai River is part of a major drainage system spanning 270km and includes several important tributaries: Sirumalaiyar, Manjalar, Varahanadhi, Theniar, Varattar-Nagalar, Suruliar, Sathiyar, and Uppar.) Geomorphologically (Figure 3) the study area consists of a well-developed network of fluvial, fluvio-marine, Aeolian and marine geomorphic landforms. The upper portion of the basin is covered by structural hills and valleys, active flood plains, pediments and valley fills. In the prodelta part of the Vaigai river, an older deltaic plain and beach ridges are extensively developed. Dunes are often found to overlie the beach ridges in several places. The occurrence of numerous crescent-shaped tanks is a peculiar phenomenon associated with this delta. The delta predominantly consists of fluvial depositional landforms. The critical analyses of the morphology of the tanks have indicated that most of these tanks are human-made and further stand as evidence for the ingenuity of the inhabitants in this rain shadow region who converted the natural depressions of the oxbow lakes, paleochannels, interlobal depressions, paleo swales, etc into the structures (tanks) for storing the excess runoff of the Vaigai river during the rainy seasons.

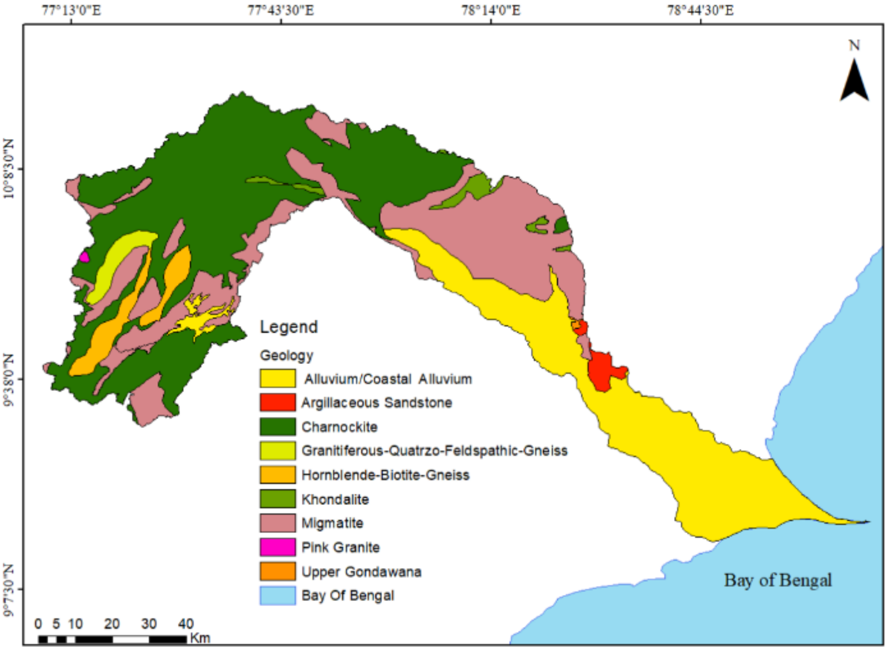

Figure 2. Geology of the study area

Geological map of the Vaigai River basin; Vaigai river basin is covered by hard crystalline rock masses of Archaean age on the western portion; mostly covered with charnockite-Migmatite-gneiss. From Manamadurai to the Bay of Bengal, rocks of upper Gondwana, teritiary alluvium and coastal alluvium are spread over the Archaean formations unconformably.

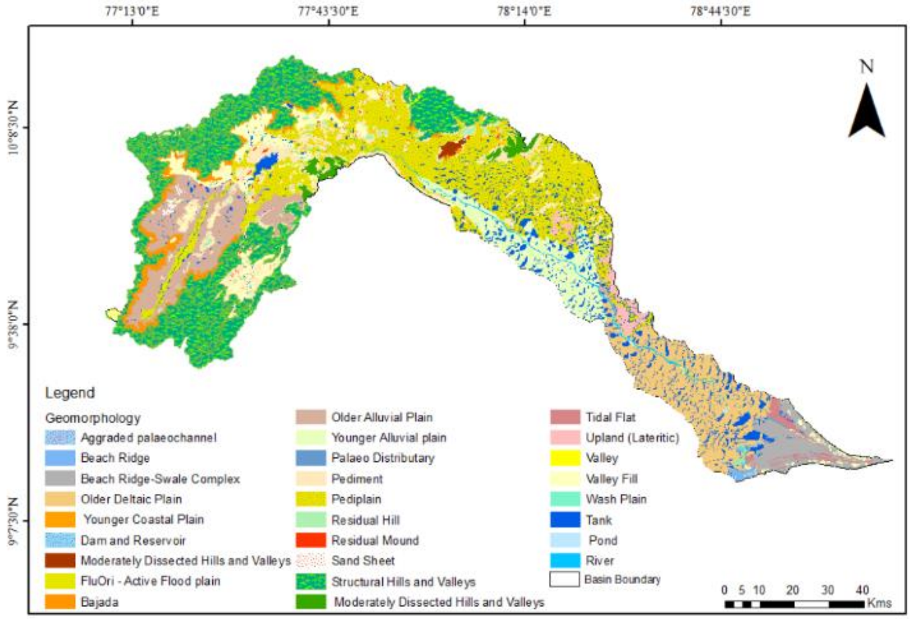

Figure 3. geomorphology of the study area

3. METHODS AND MATERIALS

The study utilized synchronized data collected from published literature. This data was employed to create and interpret longitudinal profiles and to identify significant knick points. Additionally, the collection and compilation of secondary data sources, including thematic maps on geology and geomorphology, were accomplished using ArcGIS 10.5. It was followed by other geomorphic indices of active tectonism and spatial analysis. These were supplemented with limited field checks wherever found necessary. Comprehensive analyses of the data were conducted to investigate spatial variations of tectonically active and quiescent regions. The study aimed to elucidate the relative controls on these variations, including factors such as structure, climate, lithology, and more (Source: https://bhuvan.nrsc.gov.in).

3.1 Longitudinal Profile

The longitudinal profile (Lp) is a cross-sectional representation of the channel reach and is measured in a linear direction downstream. It refers to the elevation of the river's surface in relation to the distance from its source to the mouth. Analysing the longitudinal profile provides valuable insights into historical climate patterns, river flow rates, sediment transportation, and the influence of tectonic activity on a particular region (Leopold et al., 1964; Das et al., 2018). Vaigai and its tributaries, such as Sirumalaiyar, Manjalar, Varahanadhi, Theniar, Varattar-Nagalar, Suruliar, and Sathiyar, were manually digitized using GoogleEarth Pro software to create a digital elevation profile. To generate the longitudinal profile of the river, data points at intervals of 1 km and their corresponding elevations were collected. The data were then exported to Excel software, and the longitudinal profiles were plotted for the main channel and its major tributaries. Knickzones, identified through longitudinal profiles, were documented and recorded. The sub-basins of Vaigai such as Suruliar (SRL), Varahanadhi (VRN), Theniar (TNR), Upper Vaigai (UVR), Manjalar (MJR), Varattar-Nagalar (VNR), Sirumaliar (SMR), Uppar (UPR), Satiyar (STR), and Lower Vaigai (LRV) were delineated from the Toposheets (Figure 4).

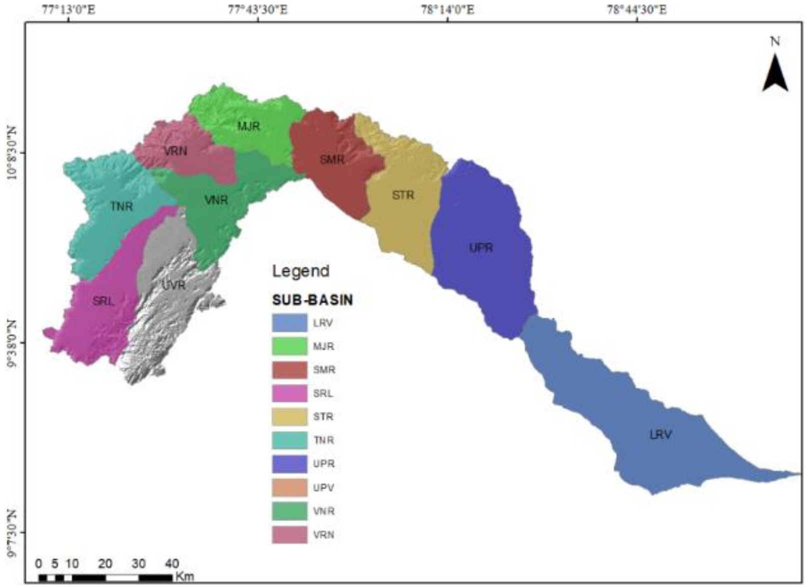

Figure 4. Sub-basins of Vaigai River Basin

3.2 Asymmetric Factor (Af)

The asymmetry factor (Af), which is sensitive to tilting perpendicular to the downstream direction of a stream, can be used to determine the tectonic tilting of a catchment (Hare and Gardner, 1985; Flores-Prieto et al., 2015; Das S, 2020). An asymmetry factor value close to 50 indicates the absence of tilting, whereas deviations of Af values (above or below 50) indicate the extent of tilting caused by lithological or tectonic influences. The asymmetry factor can be interpreted as a measure of basin asymmetry (Keller and Pinter, 2002, Das S, 2020). It is calculated by using the equation (1)

$$Af = (Ar / At) \times 100 \quad (1)$$

The Ar is the area of the basin on the right side of the main trunk stream and is the total area of the basin (Cox, 1994).

3.3 Transverse topographic symmetry factor (T)

The T factor analyses the symmetry of the basin. It is the ratio between Da (distance from the midline of the meander belt to the midline of the river basin) and Dd (distance from the basin divide to the basin midline). The T factor helps to investigate the lateral tilting of a river basin for its mainstream. Tectonically inactive zones create a perfect symmetric basin with a *T* value of 0. The tectonically active zones, dependent on tectonic intensity, create asymmetric basins with *T* value more than 0.0 and up to 1.0 (Cox, 1994). The values close to 1.0 indicate the river is flowing nearly to the basin boundary, possibly formed by severe and recent tectonic activities. Such breaks on the longitudinal profiles are generally associated with uplift or geological or structural control.

Basin midline, Da and Dd, were digitized by using Arc GIS tools and calculated by the equation (2) herein:

$$T = Da / Dd \tag{2}$$

3.4 Basin elongation ratio (BE)

The basin elongation ratio is an important geomorphic index that confirms a drainage basin's neotectonic activity. It is a dimensionless quantity calculated as the ratio of the greatest basin to a circle with a diameter equal to the area of the basin under consideration (Bull and McFadden, 1977, Gupta et.al., 2022). The value of BE is calculated by the equation (3)

$$BE = 2(A/\pi)\ 0.5/\ Bl \tag{3}$$

Where A and Bl are the area and maximum length of the basin, respectively.

3.5 Stream sinuosity (SS)

Stream sinuosity can be regarded as a significant indication of tectonic activity in a region. The curvilinear ratio of a stream's length, or the index of stream sinuosity, can be used to determine the length of the straight line connecting the two ends of the chosen channel reach, and the path. Calculated by equation (4) herein:

$$SS = CL/ L \tag{4}$$

Where *CL* is the length of the stream channel and *L* is the straight line joining the two ends of the channel (Mueller, 1968).

3.6 Circularity ratio (CR)

The circularity ratio (CR), is assessed to determine the drainage basin's shape. The circularity ratio (CR) of the basin was calculated by equation (5) herein:

$$CR = 4\pi A / p2 \tag{5}$$

Where A and P are the basin's area and perimeter respectively.

3.7 Field logging and primary data collection

The latitude and longitude of the knick points have been collected and recorded in an Excel sheet. Systematic fieldwork was conducted from the catchment area to the confluence of the trunk stream and all its tributaries. Field photographs of selected knickpoints were taken and verified on-site. Drainage basins and stream networks are delineated with the help of Toposheets and Google Earth data using ArcGIS 10.5. An examination of river channels and basins using the above-mentioned methodologies is performed in this paper to demonstrate the general geomorphic characteristics and structural control over the basin.

4. RESULTS

Figure 5 presents the spatial distribution of the knickpoints in the trunk river, as well as in the major tributaries of the Vaigai River, with lineaments overlaid by the geology. Knickzones, identified from longitudinal profiles and confirmed by field observations, have been methodically recorded with reference to their altitude above base level and the lithology gradient.

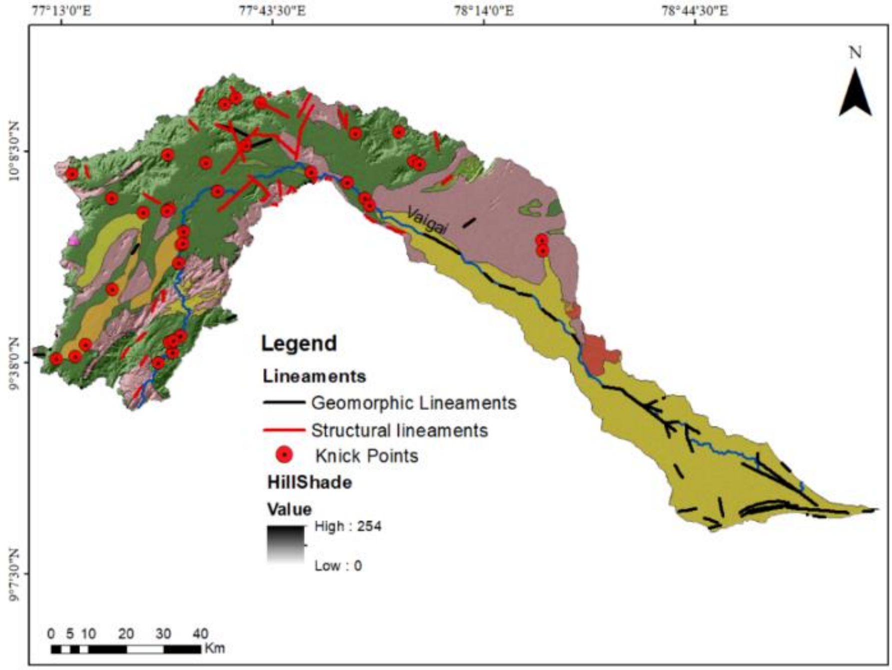

Figure 5. Location of knick points

A small part of the catchment region shows several continuous knick points, while most of the trunk river exhibits no topographic change. The river forms in former valleys and experiences an initial fall, followed by a monotonous flow for its entire length. The Vaigai River and its tributaries display uneven longitudinal profiles with numerous knickpoints along them. All the tributaries and the trunk channel show a linear fit towards the downstream (Figure 5a, 5b, 5c, 5d, 5e, 5f, 5g). The profile of Varahanadhi exhibits significant disruption, as indicated by the high R^2 value of 0.99 (Figure 5d). Similarly, the tributaries, namely Marudhanadhi, which is a major tributary of Manjalar stream within the Manjalar sub-basin (MJR) and Satiyar (STR) also demonstrate the incision with R^2 values of 0.98 (Figure 5f and 5c). Field verification confirms that the Vaigai River also exhibits incision (R^2 = 0.95) at various locations (Figure 6a). The Suruliar falls, and Thalaiyar falls (Figure 6b) are the major knick points in the Vaigai River Basin. Thalaiyar waterfall is the steepest and highest waterfall, nearly 820-meter elevation in the Manjalar stream. The calculated asymmetry factor (Af) of the entire Vaigai River Basin is 45, resulting from drainage basin tilting, either due to tectonic activity or to lithological control. The T factor for the Vaigai River Basin is calculated at different segments of stream channels (Figure 7). The computed value of the transverse topographic symmetry factor ranges from 0.18 to 0.87 but most of the computed values lies within the range of 0.53 to 0.59 (Table 1). The mean value of the entire basin is 0.55. The mean values of the asymmetry factor for sub-basins are 48.06. The 'T' factor values of the sub-basins vary from 0.17 (LRV) to 0.79 (SRL). The maximum Af for SMR (53.34), UVR (51.83) and LRV (51.38) shows an asymmetry value of more than 50, with all others having a value less than 50 (Table 2).

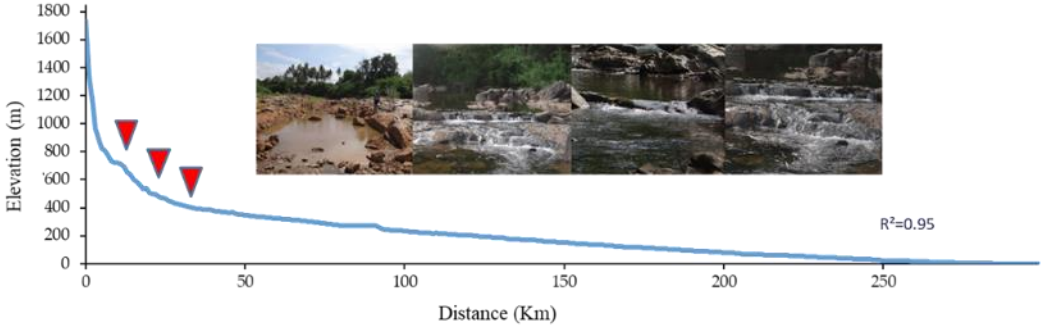

Figure 5a. Vaigai

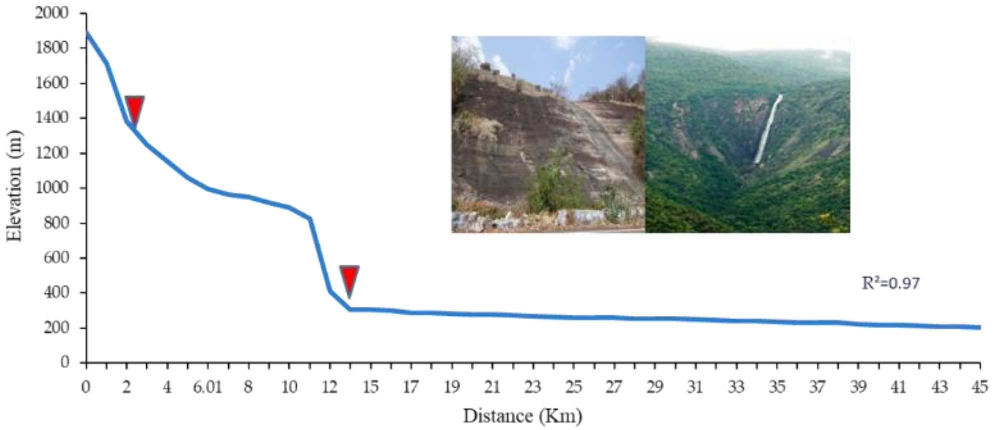

Figure 5b. Manjalar

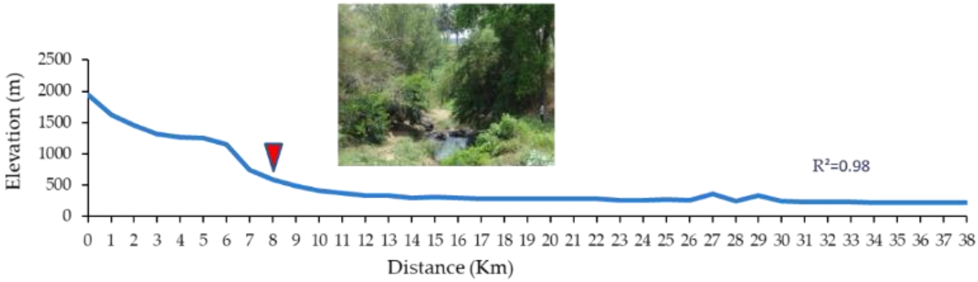

Figure 5c. Marudhanadhi

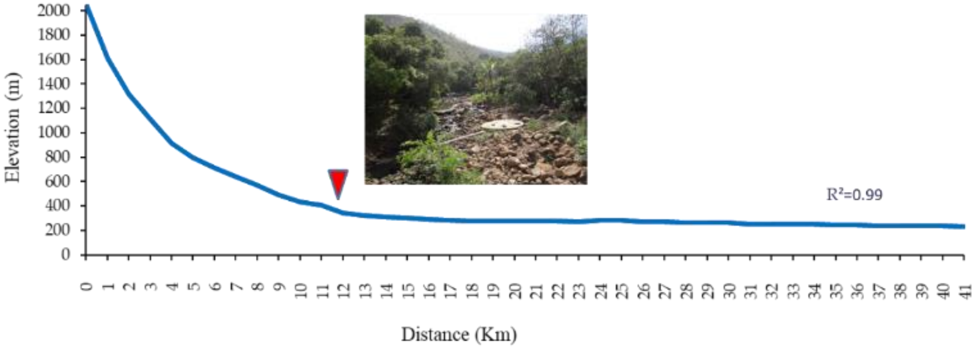

Figure 5d. Varahanadhi

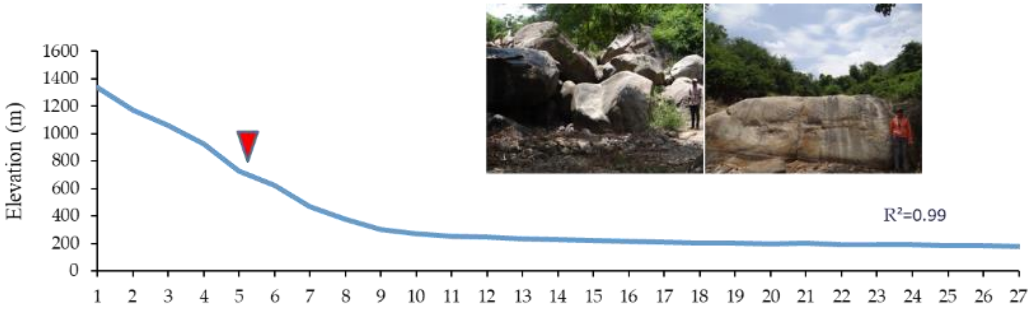

Figure 5e.Sirumalaiyar

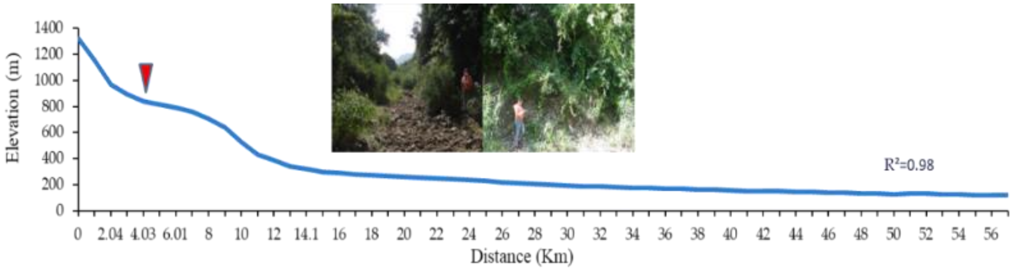

Figure 5f. Sathiyar

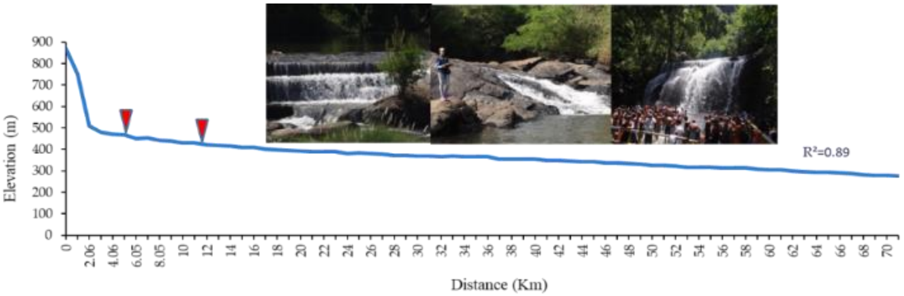

Figure5g. Suruliar

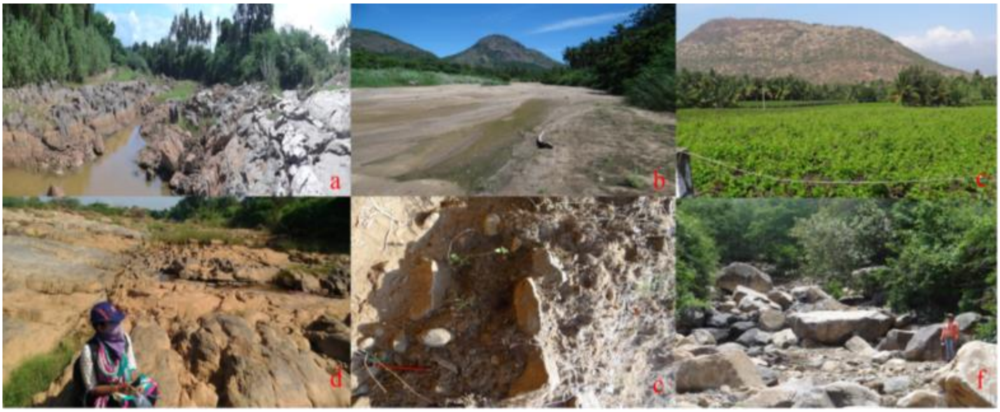

Figure 6a. Field Photographs showing Incision and tectonic characteristics, a)&d) Bedrock channel with riffle-chute structure, suggestive of intensive erosion as a result of tectonic and fluvial activity b) Meandering of stream in a high altitude region as a result of tectonic activism and channel course shift c) "L"-shaped landscape morphology evidencing inheritance of palaeolandscape, continuation and recent activism d) Bedrock channel with riffle-chute structure, suggestive of intense erosion as a result of tectonic and fluvial activity e) Alluvial Fan f) (Sirumalaiyar) Its a bed rock channel having boulder to pebble sized sediments.

In the present study, the BE value for the sub-basins is ranging from 0.34 to 0.53. Basins SRL, UVR, LRV, MJR and STR have the BE values 0.35, 0.40, 0.34, 0.50, 0.41 respectively and the rest of the basins such as VRN, SMR, TNR, VNR, and UPR, obtained BE values of 0.52,0.51, 0.53,0.53,0.53 respectively. The sinuosity of the Varattar-Nagalar River corresponds to a low SS value (1.14). The SS index has a minimum value for stream UVR of (0.80) and a maximum value for basin Manjalar of 1.66. The circulatory ratio (*CR*) calculated in this study lies from 0.27 (Basin VNR) to 0.67 (Basin UPR). The CR calculated the whole basin is 0.14. The sub-basins such as VRN, TNR, SRL, UVR, MJR, SMR, LRV, and STR show values 0.52, 0.41, 0.29, 0.33, 0.45, 0.54, 0.32, 0.39 respectively (Table 2). The spatial distribution map (Figure 8) for indices clearly says that sub-basins fall under the low to moderately active class. SMR almost shows a high value of geomorphic indices. The sub-basin LRV has low values of geomorphic indices. The T factor for sub-basin UPR, VNR, SRL, SMR, UVR, MJR, STR, and VRN, ranges from 0.37-0.79 except TNR, LRV. The

SS value is <1.05 for the sub-basin LRV and UVR. MJR has an SS value >1.50, while all other sub-basins range from 1.05-1.50. TNR, MJR, UPR, and VNR sub-basins have the BE value ranging from 0.51-0.53 and others fall in the range of 0.34-0.50. Most of the sub-basins have the CR value <0.4 while the VRN and SMR range >0.5. The Af factor obtained for UVR, SMR, and LRV is >50.

Figure 6b. Major Knick points, a) Knick point in Suruliar tributary b) Location Uthamapalayam c) Suruli falls near Cumbum d) Thalaiyar falls

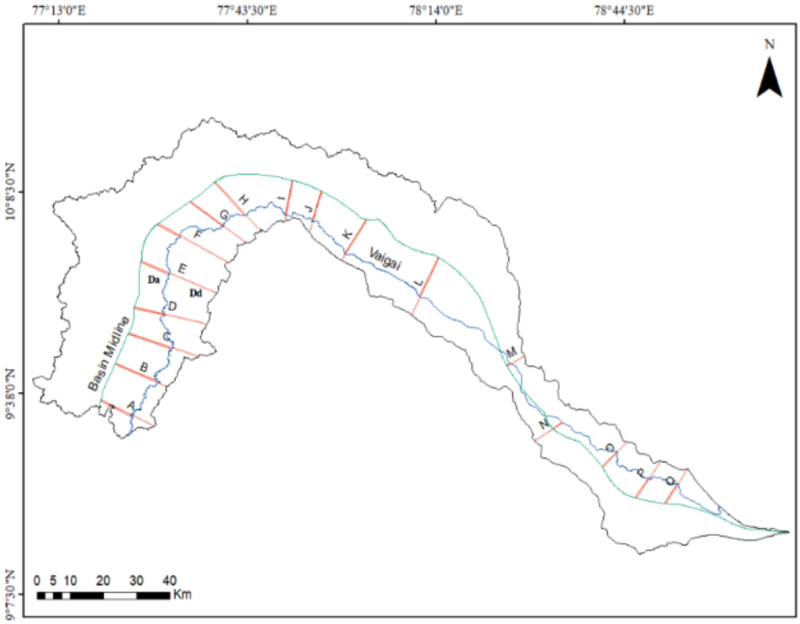

Figure 7. Transverse topographic asymmetry (T) of Vaigai River Basin.

Table 1: Transverse topographic asymmetry (T) of Vaigai basin, Da = Distance between active channel and basin midline; Dd = Distance between basin divide to basin midline

Transact	T=Da/Dd
A	0.55
B	0.87
C	0.42
D	0.42
E	0.36
F	0.32
G	0.59
H	0.67
I	0.85
J	0.73
K	0.84
L	0.68
M	0.18
N	0.34
O	0.59
P	0.53
Q	0.57
Mean	0.559412

Table 2: Basin Elongation ratio (BE), Sinuosity Index (SS), Circularity Ratio (CR), Asymmetry factor (Af), Transverse topographic symmetry (T)

Sub-basin	BE	SS	CR	Af	T
VRN	0.52	1.37	0.48	48.13	0.77
TNR	0.53	1.36	0.41	43.95	0.27
SRL	0.35	1.3	0.29	46.58	0.79
UVR	0.4	0.8	0.33	51.83	0.52
MJR	0.5	1.66	0.45	45.87	0.45
VNR	0.53	1.14	0.27	48.91	0.77
SMR	0.51	1.25	0.54	53.34	0.73
LRV	0.34	0.91	0.32	51.38	0.17
UPR	0.53	1.2	0.67	47.19	0.47
STR	0.41	1.33	0.39	47.99	0.37

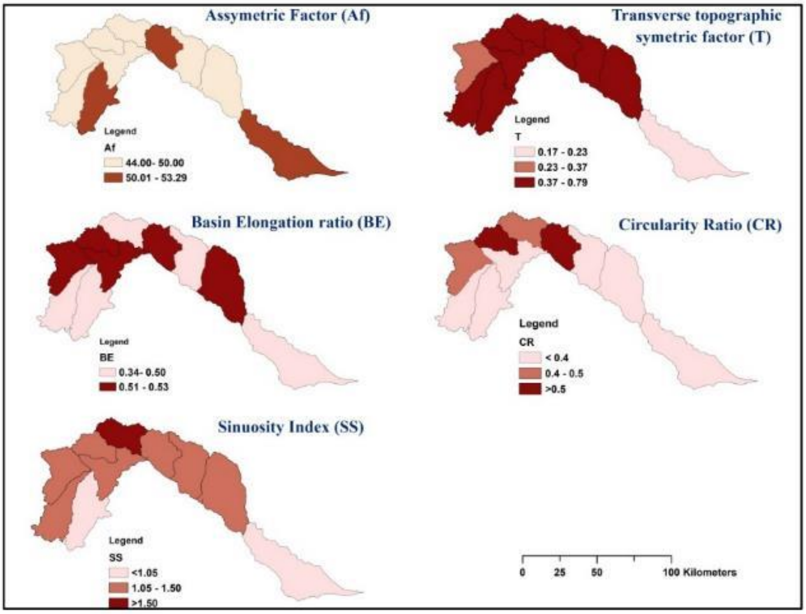

Figure 8. Asymmetric factor (*Af*), Transverse topographic symmetry (*T*), Basin elongation ratio (*BE*), Circularity Ratio (CR), Stream sinuosity (*SS*)

5. DISCUSSION

A comprehensive theory of coupled tectonic deformation and river incision would provide a method for converting between uplift rates, incision rates, and the geometry of river profiles. This would reveal details about local and regional uplift histories and, consequently, the underlying tectonic history (Royden and Perron, 2013). The longitudinal profile analysis of the tributaries of the Vaigai River Basin sheds light on the effect of tectonism in shaping the river profile, and similar studies have been attempted by many researchers (Bishop et al., 2005; Ambili and Narayana, 2014; Reddy, 2021). The tributaries of the Vaigai River drainage basin do not show much variation in the longitudinal profile, and the variation in lithology is limited in the basin. Hence, the differences in base level and tectonics may be the causative factors for the sudden change in the slope gradient. In the upper reaches of the stream profile, major knickpoints are evident, and tectonics plays an important role in their formation. According to Ramkumar et al. (2019), a stream in equilibrium has a concave-up longitudinal profile, but a knickpoint is a break in the gentle curve often identified by a convex reach. Similarly, the longitudinal profiles of both the trunk stream and tributaries show a linear fit and gentle slope towards the downstream, while the upstream exhibits numerous knickpoints. The Vaigai River flows on a former valley, and its distinctive direction was brought about by periodic tectono-morphological events influenced by an inherited Proterozoic structure (Ramkumar et al., 2016, 2019).

According to Ramkumar et al. (2019), the 270-km long Vaigai River has a more concave shape, with an R^2 value of 0.76. There are two knickpoints at the upper reaches of the stream, causing a convex shape in the longitudinal profile (Lp), while it shows a linear fit towards the downstream. The "Goodness of Fit" (R^2) serves as an indicator of the maturity of a drainage basin. During the equilibrium stage of a stream, its slope demonstrates a linear relationship and exhibits a high R^2 value, aligning with the concave longitudinal profile of the basin's mainstream. The interplay between intrinsic and extrinsic factors influences the migration of the knickpoints along the longitudinal profile, temporarily disrupting the linear fit in the slope-area profile. To comprehend the rock uplift and river incision, we have investigated the longitudinal profiles of both the trunk stream and its tributaries. Field verification confirms the incision of tributaries such as the Satiyar and Marudhanadhi, as evidenced by their high R^2 values of 0.98 (Figure 5f & 5c). Similarly, the Vaigai also exhibits incision (R^2= 0.95) at various locations (Figure 6a). Knickpoints frequently occur in tectonically active areas at similar elevations along with the incision wave, as supported by (Das et al., 2020). Although the Thalaiyar waterfall is the steepest knickzone, its nearly 820-meter elevation is situated in the Manjalar stream. This waterfall shows evidence of a palaeo-terrace, typical faulting of the palaeo-valley, and recent incision, forming terraced and waterfall morphology. The synergized results of geomorphic indices and field evidence show that the basin is tectonically active. The transverse topography symmetry also reflects the basin has been affected by the tectonic forces while changing its course from almost northwest–southeast direction. Knick points, deeply incised valleys, are the common features of the basin that point out the neotectonic activity in this region. AF values significantly above or below 50 result from drainage basin tilting, either due to tectonic activity or lithological control (El Hamdouni et al., 2008). Here, the T factor indicates the asymmetric nature of the basin, with tectonic tilt in the upper part of the basin indicating a more asymmetric pattern than the lower end, having T values of 0.84, 0.85, and 0.87 approaching 1. Bravard et al. (1997) found that river incision, a common occurrence in regulated rivers downstream of dams, can decrease habitat heterogeneity. Both tank and river irrigation in the Vaigai Basin are mentioned in the Sangam literature when referring to paddy agriculture. Initial dam constructions involved temporary structures. Inscriptions from the period of the Madurai Pandyas and Chola Kings (A.D. 750–A.D. 1300) provide evidence that the expansion of tanks, as well as the improvement of the dam and channel system, led to the significant advancement of irrigated agriculture during their reign (Ludden, 1979). Similarly, many dams have been constructed along the streams, such as the Vaigai dam, Marudhanadhi dam, Satiyar dam, Manjalar dam, Sothuparai dam, etc., and check dams are also present. The construction of dams and tanks may affect and disturb river flow regimes, resulting in changes in sediment transport processes and differences in geological settings (Charoenlerkthawin et al., 2021). The tectonically active zones are basins with BE values below 0.50, slightly active zones between 0.50 and 0.75 and active zones above 0.75 (Bull and McFadden, 1977, Gupta et.al., 2022). The values of BE obtained in the present study were divided into three classes (Mahmood and Gloaguen, 2012) high, moderate, and low tectonic activity as Class 1 (0.477–0.502), Class 2 (0.503–0.664), and Class 3 (0.665–0.684), respectively. Here, the basins underwent high to moderate tectonic effects. In the present study, sub-basins fall under the active to slightly active class, with values ranging from 0.34 to 0.53. Basins SRL, UVR, LRV, MJR, and STR are represented as high tectonic active areas, covering an area of approximately 4055.46 sq.km. The basins VRN, SMR, TNR, VNR, and UPR fall under the category of moderate tectonic areas, with a total area of 3325.14 Sq.km. Very high transverse topographic symmetry factor values were obtained for sub-basins SRL (0.79), VNR (0.77), and SMR (0.73), indicating that they are tectonically and structurally controlled. In contrast, the least value was observed for sub-basin LVR (0.17) as indicated in Table 2. On the contrary, higher values indicate the asymmetry of the river due to a significant shift away from the basin midline. According to Taesiri et al. (2020), the SS values were dispersed spatially and divided into three classes: Class 1 (1.114–1.171), Class 2 (1.172-1.450), and Class 3 (1.451-2.102). While a low value of SS suggests that the basin region is dynamic, a high value of SS indicates that the river is tectonically stable and closer to equilibrium (Mueller, 1968). The sinuosity of the Varattar-Nagalar River corresponds to a low SS value (1.14) and therefore falls under Class 1 (1.11–1.17). Sub basins such as VRN, TNR, SRL, SMR, STR, and UPR have SS values of 1.37, 1.36, 1.30, 1.25, 1.33, and 1.20, respectively, indicating that these streams fall under Class 2 (1.18–1.45) with moderate tectonics. Class 3 (1.46–2.10) comprises the stream Manjalar, showing a value of 1.66, revealing a low active zone. According to Anand and Pradhan (2019), the values of CR were divided into three separate active tectonic classes: Class 1 (0.122-0.207), Class 2 (0.208-0.264), and Class 3 (0.265-0.301), which stand for high, low, and moderate CR values, respectively. A circular basin with a high value of CR tends to become stretched over time. The LRV, UVR, STR, TNR, MJR, SMR, VRN, and UPR basins have CR values of 0.32, 0.33, 0.39, 0.41, 0.45, 0.48, 0.54, and 0.67, respectively, indicating that they tend to become stretched over time, while the SRL and VNR fall under Class 1, showing values of 0.29 and 0.27, respectively. Moderate values of CR for both basins indicate mature topography, and the SRL basin is comparatively elongated compared to VNR. The entire Vaigai basin shows a CR value of 0.14.

6. CONCLUSION

The Vaigai River Basin possesses an unusual configuration at basin scale, with the present-day river channel running on an antecedent basin/valley and interrupted by major crustal-scale structures that are active since the Precambrian era. Superimposed on this are the episodic activeness of tectono-climatic pulses, within which historic-modern land-use dynamics impart differential rates and scales of landscape evolution. By utilizing geomorphic indices, particularly basin asymmetry, T index, longitudinal profile, and SS, one can enhance the detection of tectonic disturbances that have taken place in a particular region. These indices serve as valuable tools for identifying active tectonic zones and evaluating anomalies in drainage patterns, thus aiding in reconnaissance efforts. In the present study, the longitudinal profile and geomorphic indices, together with field data, are calculated using spatial analysis and statistical tools. The concavity of a river profile remains unaffected by lithology, indicating that river morphology is primarily influenced by the rate of uplift over spatial and temporal scales. Longitudinal profile analysis of the tributaries of the Vaigai River suggests that base-level changes may influence the evolution of channel profiles. As most of the streams flow through uniform lithology along their profiles, we can infer that these knickpoints are structurally controlled. Each index is classified into three classes, ranging from high, moderate, and low, and analysed for the active tectonics of the study area. Also, each of the sub-basins shows low to moderate tectonic effects with respect to various geomorphic indices. The circularity ratio indicates a low to moderate level of structural control in the study area, while the basin elongation ratio indicates a high to moderate level of structural control over the basin in the study area. The value of Af indicates the presence of tectonic activity in some of the sub-basins. The transverse symmetric factor (T) suggests a tectonically and structurally controlled environment.

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