Journal of Indian Geomorphology
Volume 12, 2024 ● ISSN 2320-0731
Indian Institute of Geomorphologists (IGI)

Quantitative Morphometric Analysis and Identification of Drainage Pattern of an Upstream Sub-Basin of the Kaveri River from Bhagamandala to Shivanasamudra in a Metamorphic Terrain

Samarth Urs M., Prakash Narasimha K. N., Suresh Kumar B.V., Nagendra P. and Vinay C.
Department of Studies in Earth Science, University of Mysore, Manasagangotri, Mysore – 570006
E-mail: murssamarth@gmail.com (Corresponding author)

Abstract: *Quantitative morphometric analysis of drainage patterns has been carried out to understand the hydro-geological characteristics of a sub-basin of the Kaveri river in its upper section in relation to terrain features and flow patterns. The various drainage patterns have been identified in this upper sub-basin to understand the presence of any tectonic activity. The sub-basin is nearly circular, and the Kaveri river's highest stream order herein is nine. The upper sub-basin has a large number of streams because of the ambient low infiltration capacity and high run-off from within the metamorphic terrain. The upper sub-basin has moderate to high flood potentiality. The identification of the drainage network has given primary evidence of tectonic activity. Trellis, dendritic, rectangular, and radial drainage patterns have been identified at different places inside the sub-basin. The initial catchment area has developed a trellis drainage pattern on the ridge, indicating marked structural control. Rectangular drainage pattern is identified near the end point of the study area. A significant fault involving the basement is observed downstream of the sub-basin surrounding the Shivanasamudra and Hogenakkal falls. This has resulted in developing a rectangular drainage pattern. The presence of pseudotachylites serves as evidence for a fault event. Also, a radial drainage pattern can be observed around a dome. This shows that, there has likely been a tectonic disturbance in these two locations during the geological past.*

Keywords: Morphometric analysis, drainage pattern, tectonics, fault, metamorphic terrain

Introduction

The Kaveri river originates in the Western Ghats in the Brahmagiri forest area and flows east through Karnataka, Tamil Nadu, Kerala, and Puducherry (Punithavathi *et al.,* 2011), before converging with the Bay of Bengal. The studied sub-basin (comprising the upper portion of the Kaveri catchment) was delineated using the basin tool in Arcmap and the study area starts at the Tala-Kaveri/ Bhagamandala and ends at the Shivanasamudra falls. It lies between latitudes 11°54′27.5″ N and 13°19′59.24″ N and longitudes 75°30′ E and 77°38′57.64″ E (Fig. 1)

Streams are one of the potent natural agents on the Earth's surface, contributing to creating different landscapes and various geomorphological features (Thakuriah, 2021). These fluvial geomorphological features are either erosional or depositional; creating dynamic features, which form at different stages of the river (Liu *et al.,* 2019). The creation of drainage pattern also depends on the climate, temperature differences, underlying rock type and water availability (Alabyan *et al.,* 1998). The rocks can be either hard or soft depending on the amount of weathering in that place. Hard rock resists erosion and soft rock gets eroded very easily. Weathering of rocks also makes certain rocks weak, giving rise to more number of streams. The study area is a mixture of humid and dry (sub-humid) region. The average temperature ranges from 25°C to 40°C. In the area where the river originates, it is highly humid and in the downstream part, it is mostly dry because it falls in a rain shadow area (Thomas, *et al.,* 2015).

The morphometric properties of the river can be quantified through their linear, areal, and relief features. The river sub-basin selected for the analysis of the drainage basin is in the upstream part of the Kaveri river basin (Asode *et al.,* 2016).

Understanding the evolution of the stream or river pattern can be done only by measuring the geometry of surface morphological features and the tectonic activity (Kale *et al.,* 2014; Vaidyanadhan, 1971). Upliftment or tilting of a particular region creates certain types of drainage pattern. The drainage pattern of any river basin gives information about whether any regional structural disturbances

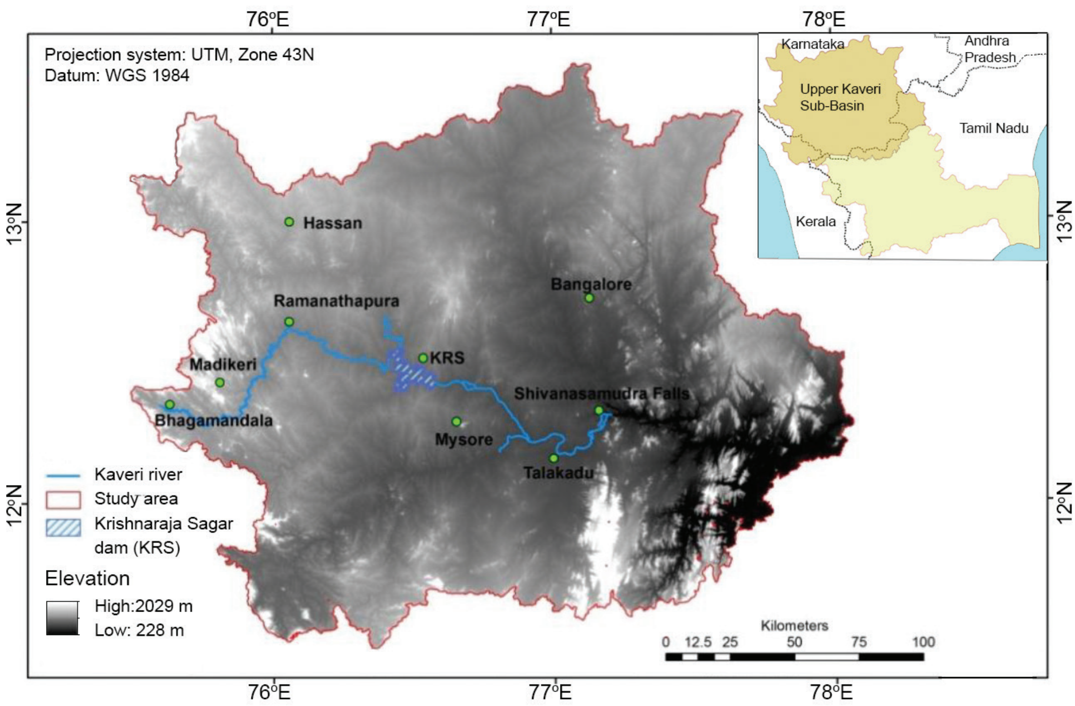

Figure 1. Study area showing upper Kaveri sub-basin.

and tectonic activity has happened in the study area. Similarly, it also reveals the nature of the underlying rocks. The tectonic activity can be older or neo-tectonic in nature (Ramkumar *et al.,* 2019).

The objective of the study is to identify and examine the types of drainage patterns in the upper catchment and some part of the flat land having gentle slope of the Kaveri river sub-basin (from Tala-Kaveri to Shivanasamudra) of Karnataka using GIS, to comprehend how the landscape evolution has shaped the river.

Geology of the study area

The Kaveri river originates in the Western Ghat in the southern granulitic terrain of Coorg district (Santosh *et al.,* 2015). The river primarily flows on metamorphic terrain (Chidambaram *et al.,* 2018). These correlate with the Precambrian rocks according to the stratigraphic record. Rocks have undergone granulite facies metamorphism along with a few patches of igneous rocks (Nutman *et al.,* 1992). The southern part of the Western Ghat, where the river originates, is made up of Charnockites derived from gneiss (Taylor *et al.,* 1984). As the river exits the Western Ghat further into a terrain with a more or less gentle slope, a mixture of gneiss and Charnockite is observed in places like Kushalnagara, Periyapattana, Ramanathapura, and other places (Sharma and Rajamani, 2001).

Further, several patches of gneiss, cross-cut with mafic dykes such as diabase, gabbro, norite are encountered in Hunsur and Mysore taluk (Sharma and Rajamani, 2000). Chamundi granite is the igneous emplaced pluton mainly found in and around Mysuru city. The basement rock, migmatites, metagabbro, quartzite, garnet biotite schist, metapelites, younger granites,

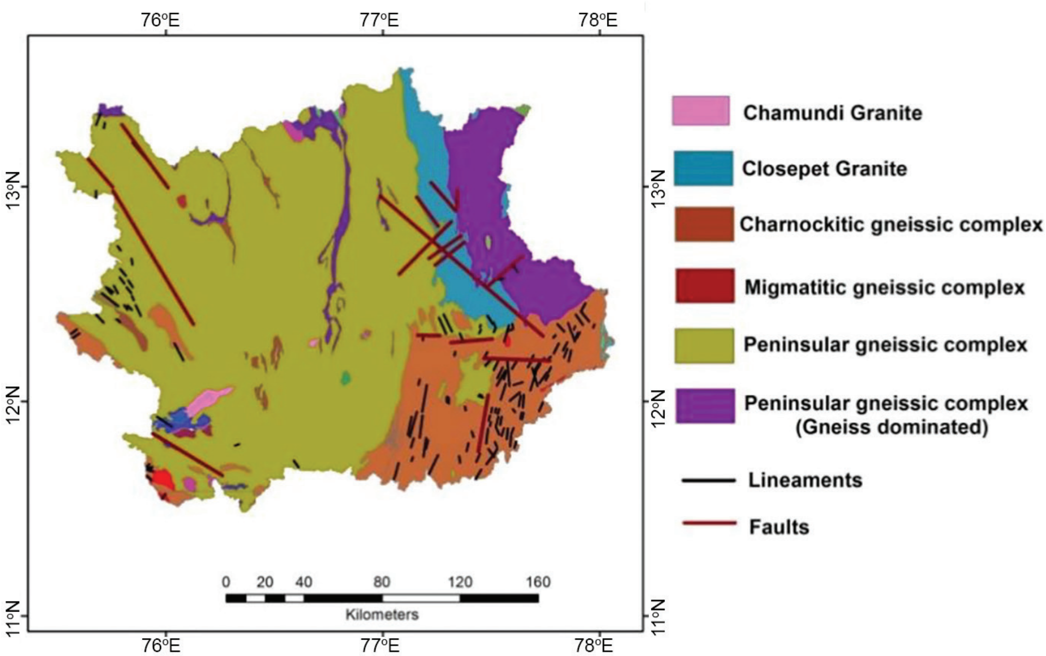

Figure 2. Geological map of the Kaveri river basin (Source: Geological Survey of India, 2023).

and felsites are intruded by numerous quartz and pegmatite veins (Swaminath and Ramakrishnan, 1981). Karighatta, Srirangapatna, and the surrounding areas also exhibit greenstone schist belts, being a terminal part of the Chitradurga schist belt (Narasimha and Kapfo, 2016). Towards the east, the river flows through T. Narasipura, Talakadu, Mudukutore, and Shivanasamudra falls (Fig. 2). In this region, all along the river course, gneiss, Charnockites, syenite, and amphibolites are observed (Rice, 2024). Pseudotachylites are present near the Shivanasamudra falls, indicating a high chance of tectonic activity along the river's course (Fig. 2). The rocks above have contributed to a significant portion of the sediments carried in the Kaveri river (Sharma and Rajamani, 2000, 2001).

Geomorphology and climate of the studied sub-basin

The Kaveri river originates in the Western Ghats at Tala-Kaveri at an average altitude of 1200 m. This part is characterised by a narrow stream network following the slope (gradient) depicting the youthful stage of the landform, created by denudational process. The Kaveri terminates in the Bay of Bengal in Tamil Nadu. In the upstream region, tributaries such as Harangi, Lakshmanatheertha, Kabini, Hemavathi, Arkavathy, and Lokapavani join the river at various nodes (Sreelash *et al.,* 2020). In between Tala-Kaveri and Shivanasamudra, several erosional and depositional landforms are present. Pediplain and pediment features cover the maximum area. Fluvial action and climate have been the major influential factors for landform development. This sub-basin has some portions in the Western Ghat and some portions in the Mysore plateau. Among these, the Western Ghat receive the highest annual rainfall (average 3638 mm) while the northern Mysore plateau, being in the rain shadow area, receives less rainfall compared to the state average annual rainfall of 1139 mm (Madolli *et al.,* 2015).

The elevation rises and drops based on the underlying rock character, giving rise to an undulated terrain. Downstream of the Shivanasamudra falls, the region comprises of moderate to highly dissected hills and valleys. A sudden drop in elevation results in the formation of significant rapids such as Chunchunkatte, Shivanasamudra (Gaganachukki and Bharachukki). Few waterfalls have formed mostly due to faulting (Ramkumar *et al.,* 2019). The topography is quite mountainous here, with the river width markedly less in its juvenile stage in places such as Tala-Kaveri, Napoklu, and Siddapura. In the mature stage of the landform, the width of the river increases as it enters the peneplains. Several meanders and large point bars are observed at Siddapura, Dubare, Madapura, Kaggala, T. Narasipura, and Talakadu (Aslam and Balasubramanian, 2001). Minor point bars, riffles, and linear sand bars are also observed at several places. Islands form a significant part of Kaveri river at Kaveri Nisargadhama, Srirangapatna, Mahadevapura and Mudukutore. Deep-cut gorges are observed at Shivanasamudra, Mekedatu, and Hogenakkal. Several areas along the course of the river have formed natural levees and broad flood plains to accommodate the excess water and fine-grained sediment during the monsoon season (Thangaraj and Karthikeyan, 2022). The river is primarily a bedrock river. Fluvial dynamics have played an essential role in forming and evolving the geomorphology of the area.

Materials and methods

DEM data tiles from Cartosat-1 numbered D43V_V3R1, D43W_V3R1, and D43X_V3R1 were used, having a spatial resolution of 2.5 m. The study area falls in the Survey of India topographical sheet numbered 57C, 57D, and 57G. The DEM data were projected to the Universal Transverse Mercator (UTM)

Table 1. Mathematical formulas adapted to calculate morphometric parameters.

Linear Aspects			
Basin length	Lb	Lb = 1.312×A0.568	Sreedevi et al. (2005)
Basin perimeter	P	P = Outer boundary of drainage basin measured in Km	Sreedevi et al. (2005)
Stream order	U	Hierarchical rank	Strahler (1964)
Stream length	Lu	Length of the stream in each order	Horton (1945)
Mean stream length	Lsm	Lsm = Lu/Nu, Where Lu = Total stream length of order u, Nu = Total no. of stream segments of order u	Strahler (1964)
Stream number	Nu	No. of streams in each order	Sreedevi et al. (2013)
Stream length ratio	Rl	RL = Lu/Lu–1, Where Lu = The total stream length of the order u, Lu–1 = Total stream length of its next lower order	Schumm (1956)
Bifurcation ratio	Rb	Rb = Nu/Nu+1, Nu = Total no. stream segments of order u, Nu+1 = Number of segments of the next higher order	Schumm (1956)
Mean bifurcation ratio	Rbm	Average of bifurcation ratios of all orders	Strahler (1964)
Areal Aspects			
Drainage density	Dd	Dd = Lu/A where, Lu = Total stream length of all orders and A = Area of the basin (Km^2)	Horton (1932)
Drainage texture	Rt	Rt = Nu/P, Where Nu = Total No. of streams of all orders P = Perimeter (Km)	Smith (1950)
Stream frequency	Fs	Fs = Nu/A, where Nu = Total no. of streams of all orders A = Area of the basin (Km^2)	Horton (1945)
Elongation ratio	Re	Re = 2/Lb ×$(A/\pi)^{0.5}$ Where, A = Area of the basin Lb = Basin length (Km)	Schumm (1956)
Circulatory ratio	Rc	Rc = 4×π× A/P^2, Where π = 3.14, A = area of the basin P^2 = Square of the perimeter (km)	Strahler (1956)
Form factor	Rf	Rf = A/Lb^2, Where A = Area of the basin (Km^2) Lb^2 = Square of basin length	Horton (1945)
Infiltration number	If	If = Dd×Fs Where. Dd = Drainage density and Fs = Drainage frequency	Umrikar (2016)
Length of overland flow	Lg	Lg = 1/2 Dd, Dd= Drainage density	Horton (1945)
Relief Aspects			
Basin relief	BH	The vertical distance between the lowest and highest points of the basin	Schumm (1956)
Relief ratio	(Rh)	Rh = Bh/Lb, where Lb = Basin length	Schumm (1956)
Ruggedness number	(Rn)	Rn = (Bh×Dd)/5280 Where, Bh = Basin relief, Dd = Drainage density	Hart (1964)

projection system, zone 43N and datum of World Geodetic System 1984 (WGS84). The re-projected DEM was used for extracting the drainage network.

The drainage network of the upper Kaveri sub-basin is extracted from a series of geoprocessing tools in ArcGIS-10.2. The sub-basin was created up to the end point called Shivanasamudra falls by using the basin tool in the ArcGIS. The output of this method is a basis for creating a stream/ drainage network grid with stream order based on the method of Strahler (1964). According to Strahler's classification system (Strahler, 1964), the length and frequency of the streams of various orders were first recorded for morphometric analysis. Primary morphometric parameters such as drainage area, perimeter, basin length, stream order, and mean stream length were calculated for the sub-basin area starting from the source of the river till the Shivanasamudra falls, which is near the border of Karnataka and Tamil Nadu.

These primary morphometric parameters were calculated using derived attributes like the bifurcation ratio, mean stream length, drainage density, elongation ratio, circulatory factor, and form factor. Also, relief-related parameters like basin relief, slope, and relief ratio were estimated from the DEM using mathematical formulas (Table 1). Based on the nature of drainage patterns, the present work attempts to understand whether tectonic activity has happened or not and the presence of any marked structural influence on the drainage alignment.]

Results and discussion

Basin metrics

The Kaveri sub-basin which has been delineated from the main Kaveri basin has

Table 2. Linear aspect of the study area.

Stream Order (u)		Number of streams (Nu)		Mean stream length (Lsm) in km	
1st order		62432		0.71	
2nd order		16740		1.38	
3rd order		4062		2.88	
4th order		1031		5.59	
5th order		239		11.85	
6th order		60		21.5	
7th order		15		52.33	
8th order		4		95.25	
9th order		1		184	
Stream Length ratio (Rl)					
2nd/ 1st order	0.51	5th/ 4th order	0.49	8th/ 7th order	0.48
3rd/ 2nd order	0.50	6th/ 5th order	0.45	9th/ 8th order	0.49
4th/ 3rd order	0.49	7th/ 6th order	0.60		
Bifurcation ratio (Rb)					
1st/ 2nd order	3.72	4th/ 5th order	4.31	7th/ 8th order	3.75
2nd/ 3rd order	4.12	5th/ 6th order	3.98	8th/ 9th order	4.00
3rd/ 4th order	3.93	6th/ 7th order	4.00	Mean bifurcation ratio	3.97

an area of 40,851 km^2 and a perimeter of 1714 km. The maximum elevation of the terrain is 2029 m at the source, and the minimum elevation is 236 m at the end point of the study area. The various morphometric parameters of the Kaveri river sub-basin have :been computed and summarised as follows

Linear aspects

The linear aspects, including stream order (u), stream length (Lu), mean stream length (Lsm), stream length ratio (RL), and bifurcation ratio (Rb), were determined, and the results have been presented in Table 2.

Stream order (u) and stream number (Nu)

Streams have been assigned the order based on the method proposed by Strahler (1964). The highest order stream will have high runoff and sediment transportation (Al-Saady *et al.,* 2016). The average annual discharge of the Kaveri at two discharge and sediment measuring station, viz. Kudige and Shivanasamudra, situated within this sub-basin study area, are 166 and 254 m^{3}s^{-1} respectively (source: Central Water Commission). The average annual sediment discharge of the Kaveri river at Kudige and Shivanasamudra are 40 and 50 mgl^{-1} (Source: Central Water Commission). The study area (sub-basin) has in total, 84,584 streams, out of which 62,432 are of first order, 16,740 are of second order, 4062 are of third order, 1031 are of fourth order, 239 are of fifth order, 60 are of sixth order, 15 are of seventh order, 4 are of eighth order, and one (Kaveri) is a ninth order stream. Stream numbers decrease exponentially as the stream order increases.

Stream length (Lu)

Stream length is mainly related to the discharge and surface runoff (Arulbalaji and Gurugnanam, 2017). Many streams of smaller lengths indicate higher slopes, fine texture, and impermeable bedrock. In contrast, a small number of relatively more extended lengths of streams indicates much flatter gradients and moderately permeable bedrock formation. The cumulative stream length for different orders (Table 2) of the Kaveri sub-

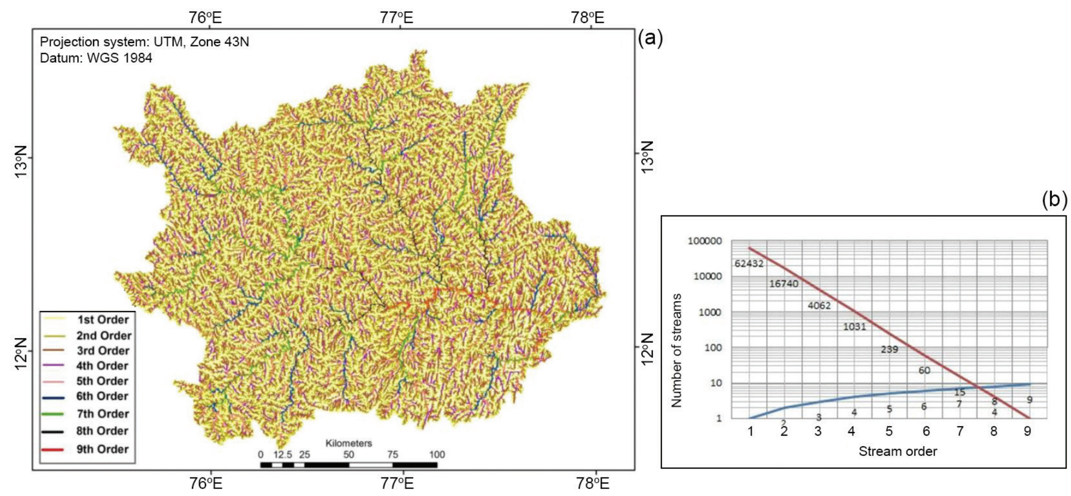

Figure 3. (a) Stream order map of the study area Strahler; 1964, (b) Relationship between number of stream and stream order.

basin are — first order (44787 km), second order (23114 km), third order (11725 km), fourth order (5765 km), fifth order (2834 km), sixth order (1290 km), seventh order (785 km), eighth order (381 km) and ninth order (189km). In the Kaveri river sub-basin, total lengths of streams were found predominantly in first, second, and third-order streams indicating maximum streams confined to the Western Ghats. This brings out a strong assumption that the sub-basin is subjected to erosion, exposing the bedrock at the base of the river bed in the pediments and peneplains along the Western Ghats. Throughout the basin the streams indicate sufficient geomorphological adjustment in the hard rock terrain. The geomorphological adjustment has taken place because there is almost no lateral movement in the river and slaking (very less erosion takes place in the meanders because of hard rock exposure) is also one of the factors.

Mean stream length (Lsm)

Mean stream length (Lsm) is directly related to the drainage network and associated basin surfaces (Strahler, 1964). The Lsm values vary from 0.71 km for 1st order stream to 184 km for 9th order stream. Relatively higher Lsm values (first, second, and third order) in the upper sub-basin of the Kaveri river indicate high erosion potentiality (Horton, 1945) due to high runoff.

Stream length ratio (Rl)

The total stream length of a given order is inversely related to the stream order, i.e., total stream length decreases from the lower order to the successively higher orders. This change might be attributed to variations in slope and topography (Pande and Moharir, 2017), indicating the late youth stage to mature stage of geomorphic development in the streams of the study area.

Bifurcation ratio (Rb)

According to Schumm (1956), the term bifurcation ratio may be defined as the ratio of the number of stream segments of a given order to the number of segments of the next higher orders. The bifurcation ratio shows a small range of variation for different regions or environments except where powerful geological control dominates (Table 2). It is considered an important parameter denoting any basin's water-carrying capacity and related flood potentiality. The variations of bifurcation ratio values are due to strong geological and lithological controls such as lineaments, weathering of rocks, faults of the upper sub-basin. Also, the average bifurcation ratio for the Kaveri river upper sub-basin is 3.97 which indicates moderate to high hilly region, moderate ground slope, moderate to high runoff, and moderate permeability of bed rocks. This indicates that the drainage pattern of the basin has been affected by the structural disturbances only near the southern end of the study area near Shivanasamudra falls (Choudhari *et al.,* 2018). When the bifurcation ratio is low, there is a higher possibility of flooding, as water will tend to accumulate rather than spread.

Aerial aspects

The area of a basin (A) and perimeter (P) are essential parameters in quantitative geomorphology. The area of the basin is defined as the total area projected upon a horizontal plane. Perimeter is the length of the boundary of the basin. Areal aspects include different morphometric parameters, like drainage density (Dd), drainage texture (Rt), stream frequency (Fs), form factor

(Rf), circulatory ratio (Rc), elongation ratio (Re), Infiltration number (If), Compactness coefficient (Cc) and length of the overland flow (Lg). The calculated values of these parameters have been included in Table 3.

Drainage density (Dd)

Drainage density indicates the closeness of the spacing of channels, thus providing a quantitative measure of the average length of stream channels for the whole basin (Horton, 1932). The average drainage density of the study area is 2.22 km km^{-2}, which is moderate, and this Dd feasibly indicates a well-drained area with moderate relief, lower rock resistivity, higher vegetation cover and moderate infiltration capacity.

Drainage texture (Rt)

Drainage texture is calculated by dividing the total stream length by the length of the perimeter of the upper sub-basin (Smith, 1950). The drainage texture of the Kaveri sub-basin is 49.34 indicating fine texture (Pant *et al.,* 2020).

Stream frequency or drainage frequency (Fs)

Stream frequency is directly related to drainage density (Horton, 1945, Rao *et al.,* 2010; Waikar and Nilawar, 2014). The stream frequency (Fs) value of the basin is 2.07 km^{-2}. The higher Fs value of the Kaveri river upper sub-basin indicates moderate rock permeability, high runoff, and increased drainage density.

Form factor (Rf)

Form factor is the quantitative expression of the drainage basin outline form. The smaller the form factor value, the more elongated the basin. The form factor (Rf) value of the study area is 0.55. This indicates that the sub-basin is nearly circular in shape. The less elongated basin with a medium form factor indicates that the upper sub-basin has a moderate flow for an average duration, depending upon the local topography.

Circulatory ratio (Rc)

Circulatory ratio is mainly related with the length and frequency of streams, geological structures, land use-land cover, climate, relief, and basin slope (Kusre, 2016; Das *et al.,* 2012; Sreedevi *et al.,* 2013). Low, medium, and high values of Rc indicate the young, mature, and old stages of the life cycle of the watershed. The Rc value of the Kaveri sub-basin is 0.17, which indicates that this upper sub-basin's elongation is intermediate, i.e., it is in-between circular and elongated shapes.

Elongation ratio (Re)

Elongation ratio is a very significant index in the analysis of the basin shape, which helps to give an idea about the hydrological character

Table 3. Aerial aspect of the upstream part of the Kaveri river sub-basin.

Bifurcation ratio (Rb)			
Area (km^2)	40,859	Stream frequency	2.07
Perimeter (km)	1714	Form factor	0.55
Elongation ratio	0.41	Circulatory ratio	0.17
Infiltration Number	4.59	Drainage texture	49.34
Drainage density (km km^{-2})	2.22	Length of overland flow	1.11

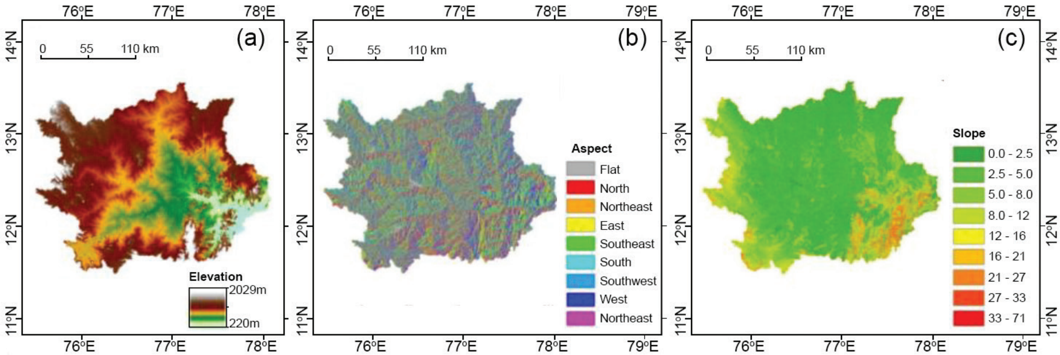

Figure 4. (a) DEM map (b) Aspect map and (c) Slope map of the upper Kaveri sub-basin

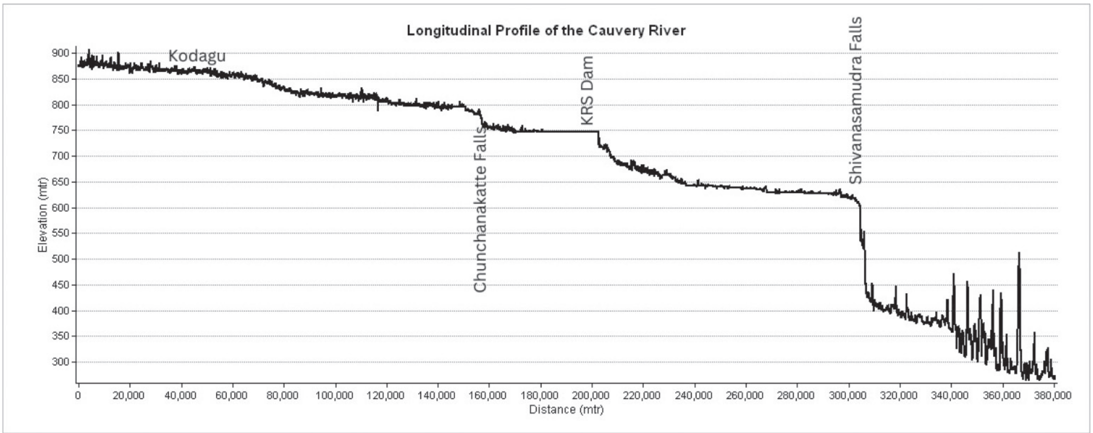

Figure 5. Longitudinal profile of Kaveri river within the study area.

of a drainage basin (Schumm, 1956). The elongation ratio value of the Kaveri river sub-basin is 0.41, which is medium. Values of elongation ratio show that sub-basin is nearly circular, whereas lower Re values are susceptible for moderate to high flood in the river and sediment transportation.

Length of overland flow (Lg)

The length of overland flow (Lg) approximately equals half of the reciprocal of drainage density. It is the length of water movement over the ground before it gets concentrated into definite stream channels. The length of the overland flow of the study area is 1.11 km km^{-2}, indicating low infiltration capacity, leading to chances of moderate to high flood potentiality.

Infiltration number (If)

Infiltration number is the product of drainage density and drainage texture, giving the idea about the permeability of the bedrock, and this is 4.59 for the Kaveri sub-basin. The infiltration capacity is moderate to high because the study area has extensive weathered and fractured rock exposures.

RELIEF ASPECTS

Basin relief (Bh)

Basin relief is the difference in elevation between the highest point of the basin and the lowest point of the basin. Basin relief depends upon the region's underlying geology, geomorphology, and drainage characteristics. The highest point and the lowest point of the Kaveri sub-basin (study area) is 2029 m near the river's source and 236 m at Shivanasamudra, which is the end point of the study area. Thus there is high basin relief in the study area of 1793 m. The Kaveri sub-basin is in-between youth stage and mature stage of development. The slope of the upper sub-basin ranges from 2.5° in the peneplained areas to 72° in the Western Ghats and in the highly dissected regions (Fig. 4).

Relief ratio (Rh)

The relief ratio generally increases with decreasing drainage area and size of the river basin (Arulbalaji and Padmalal, 2020). The relief ratio indicates steepness of the basin (Schumm, 1956), the intensity of the erosion (Chopra *et al.,* 2005; Javed *et al.,* 2009; Ajibade *et al.,* 2010), and also is a measure of potential energy available to move water and sediment (Prabhakaran and Jawahar Raj, 2018). The relief ratio of the Kaveri upper sub-basin is 3.2, which indicates high slope in the Western Ghats area and gentle slope towards east, once it exits the western flank, except for a few knickpoints (Fig. 5). Low slope is present across most of the sub-basin area and high slope is found in locales where the river originates. The peak discharge of the Kaveri river is 4074.79 m^3s^{-1} (143,900 ft^3s^{-1} according to Chow, 1964) in the monsoon season.

Ruggedness number (Rn)

Ruggedness number is the product of the basin relief and the drainage density (Hart, 1986). The study area has a ruggedness value of 0.75 indicating mature stage of denudation. This suggests the presence of metamorphic rocks such as gneiss and schist in large areas (Sharma and Rajamani, 2000, 2001).

Hypsometric curve and hypsometric Integral (HI)

It can be explicated in terms of the stage of landscape dissection and relative age of the landform. The HI is also strongly affected by basin geometry and drainage network. Walcott and Summerfield (2008) showed that the integral obtained for many basins and sub-basins along the southeastern region of South

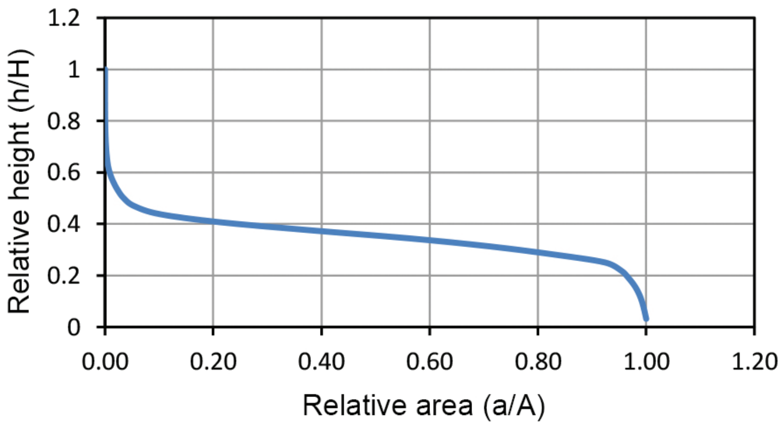

Figure 6. Hypsometric curve of the study area.

Africa did not match with basin geometry. This research signifies that hypsometry is sensitive to various natural conditions such as tectonics, lithology, and climate (Fig. 6).

The present study area has a hypsometric integral of 0.47, expressing the late youth to mature (equilibrium) stage. The starting point in the Western Ghats and end point of the study area has moderate to highly dissected landform. Most of the area in-between has a gentle slope except knickpoints.

Drainage patterns and tectonic and litho-structural influences

Identification of the present drainage pattern has helped us to primarily assess whether any tectonic activity has occurred in the upper sub-basin region or not. The study reveals the development of four types of drainage patterns at various places inside the sub-basin. The trellis drainage pattern is aligned along the strike of the ridges, with tributaries joining at almost right angles, showing marked structural control. The plucking of rocks locally has helped in erosion and weathering. It has developed near the flanks and ridges of the Western Ghats in the study area and the highly dissected area to the southwest of the Shivanasamudra falls and in its surrounding areas (Fig. 7).

Most of the region is covered by dendritic to sub-dendritic drainage patterns. This area has complex and intensely folded metamorphic terrain containing Charnockites and gneiss. At two places radial drainage pattern is observed around dome-like structures (Fig. 7).

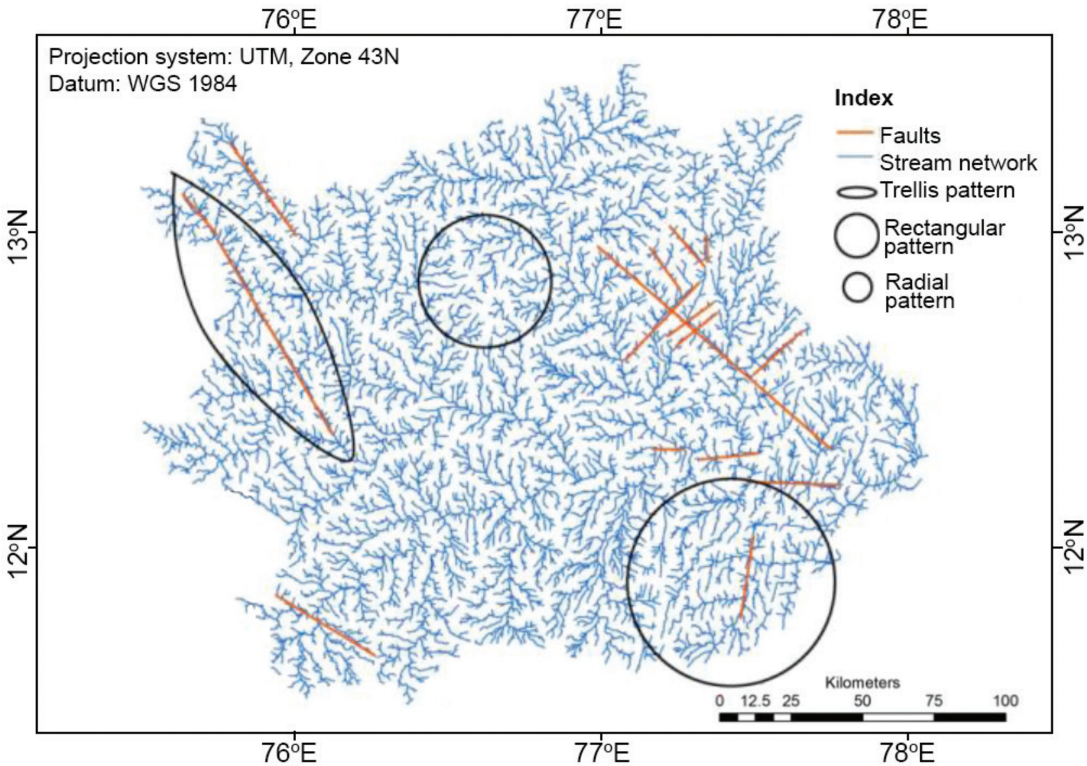

Figure 7. Drainage pattern and fault map of the study area (source of fault map: Geological Survey of India, 2023)..

A rectangular drainage basin is mainly observed at the end of the upper sub-basin from Shivanasamudra falls till Hogenakkal falls in the downstream part, just before the Mettur Dam. The presence and control of faults in that area is thus discerned.

Conclusion

As is evident from the morphometric analysis of the upper Kaveri sub-basin, stream order and stream numbers are inversely proportional. Higher order streams indicate a large amount of water received in the peneplains showing a higher possibility of flooding as water will tend to accumulate rather than spread. Low drainage density indicates a mixture of low and moderate relief, moderate vegetation cover, and moderate infiltration capacity showing moderate runoff. There is no lateral shift or change in the course of the river in the upper sub-basin area. There is a chance that tectonics and structural influences have played a tangible role in shaping the trellis drainage pattern in the Western Ghats near the origin and rectangular pattern at the end of upper sub-basin. The faults are associated with the basement rocks, permitting the cutting of deeply dissected valleys, establishing the structural control and plucking of rocks in Western Ghats and nearer to the Shivanasamudra falls (end point of upper sub-basin). The upper sub-basin has a shape between circular and elongated. All these factors have led to the evolution of the discerned drainage patterns in this Kaveri upper sub-basin. The Hypsometric integral of Kaveri upper sub-basin indicates a late young and mature stage of geomorphic development. It also indicates moderately denuded landforms. The obtained results can be utilised for hydrogeological, geomorphological and engineering geological projects in the study area.

Acknowledgements: The first author acknowledges the contributions from all the authors. The author also expresses deep gratitude to the guide, co-guide and chairman, DOS in Earth Science, for providing necessary facilities for doing this research.

References

Ajibade, L.T., Ifabiyi, L.P., Iroye, K.A. and Oguntеru, S. (2010) Morphometric analysis of Ogunpa and Ogbere drainage basins, Ibadan, Nigeria. Ethiopian Journal of *Environmental Studies and Management,* 3(1): 13–19.

Al-Saady, Y.I., Al-Suhail, Q.A., Al-Tawash, B.S. and Othman, A.A. (2016) Drainage network extraction and morphometric analysis using remote sensing and GIS mapping techniques (Lesser Zab River Basin, Iraq and Iran). *Environmental Earth* Science, 75, 1243. https://doi.org/10.1007/s12665-016-6038-y

Alabyan, A.M. and Chalov, R.S. (1998) Types of river channel patterns and their natural controls. *Earth Surface Processes and Landforms,* 23(5), 467–474.

Arulbalaji, P. and Gurugnanam, B. (2017) Geospatial tool-based morphometric analysis using SRTM data in Sarabanga Watershed, Cauvery River, Salem district, Tamil Nadu, India. *Applied Water Science,* 7: 3875–3883. https://doi.org/10.1007/s13201-017-0539-z

Arulbalaji, P. and Padmalal, D. (2020) Sub-watershed prioritization based on drainage morphometric analysis: a case study of Kaveri River Basin in South India. *Journal of the Geological Society of India,* 95: 25–35.

Aslam, M.A.M. and Balasubramanian, A. (2001) Identification of palaeochannels around Kaveri River near Talakad, Karnataka using remote sensing data. *Journal of the Indian Society of Remote Sensing,* 29: 237–242.

Asode, A.N., Sreenivasa, A. and Lakkundi, T.K. (2016) Quantitative morphometric analysis in the hard rock Hirehalla sub-basin, Bellary and

Davanagere Districts, Karnataka, India using RS and GIS. *Arabian Journal of Geosciences,* 9: 1–14.

Choudhari, P.P., Nigam, G.K., Singh, S.K. and Thakur, S. (2018) Morphometric based prioritization of watershed for groundwater potential of Mula river basin, Maharashtra, India. *Geology, Ecology, and Landscapes,* 2(4): 256–267.

Chidambaram, S., Ramanathan, A.L., Thilagavathi, R. and Ganesh, N. (2018) Cauvery River. In Singh, D.S. (ed.) The Indian Rivers: *Scientific and Socio-Economic Aspects,* Springer Hydrogeology, Springer Nature Singapore: 353–366.

Chopra, R., Dhiman, R.D. and Sharma, P.K. (2005) Morphometric analysis of sub-watersheds in Gurdaspur district, Punjab using remote sensing and GIS techniques. *Journal of the Indian Society of Remote Sensing,* 33: 531–539.

Chow, V. te. (1964) *Handbook of applied hydrology: A Compendium of Water-Resources Technology,* McGraw-Hill Book Company, New York: 1525p.

Das, A., Mondal, M., Das, B. and Ghosh, A.R. (2012) Analysis of drainage Morphometry and watershed prioritization in Bandu watershed, West Bengal through Remote Sensing and GIS technology. *International journal of Geomatics and Geosciences,* 2(4): 995–1013.

Har, t M.G. (1986) *Geomorphology—pure and applied*. Allen and Unwin Pub. Ltd., London: 211p.

Horton, R.E. (1932) Drainage-basin characteristics. *Transactions, American Geophysical Union,* 13(1): 350–361.

Horton, R.E. (1945) Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology. *Geological Society of America Bulletin,* 56(3): 275–370.

Javed, A., Khanday, M.Y. and Ahmed, R. (2009) Prioritization of sub-watersheds based on morphometric and land use analysis using remote sensing and GIS techniques. *Journal of the Indian Society of Remote Sensing,* 37: 261–274.

Kale, V.S., Sengupta, S., Achyuthan, H. and Jaiswal, M.K. (2014) Tectonic controls upon Kaveri River drainage, cratonic Peninsular India: Inferences from longitudinal profiles, morphotectonic indices, hanging valleys and fluvial records. *Geomorphology,* 227: 153–165.

Kusre, B.C. (2016) Morphometric analysis of Diyung watershed in northeast India using GIS technique for flood management. *Journal of the Geological Society of India,* 87: 361–369.

Liu, X., Shi, C., Zhou, Y., Gu, Z. and Li, H. (2019) Response of Erosion and Deposition of Channel Bed, Banks and Floodplains to Water and Sediment Changes in the Lower Yellow River, China. Water, 11(2): 357. doi:10.3390/w11020357.

Madolli, M.J., Kanannavar, P.S. and Ravindra Yaligar, R.Y. (2015) Impact of climate change on precipitation for the upper Kaveri river basin, Karnataka state. *International Journal Agricultural Science and Research,* 5: 99–104.

Narasimha, K.N.P. and Kapfo, L. (2016) Petrological and geochemical studies of felsites around Mandya district, western Dharwar craton, South India, Karnataka. *International Journal of Geology and Earth Sciences,* 2(1): 63–76.

Nutman, A.P., Chadwick, B., Ramakrishnan, M. and Viswanatha, M.N. (1992) SHRIMP U-Pb ages of detrital zircon in Sargur supracrustal rocks in western Karnataka, southern India. *Journal of the Geological Society of India,* 39(5): 367–374.

Pande, C.B. and Moharir, K. (2017) GIS based quantitative morphometric analysis and its consequences: a case study from Shanur River Basin, Maharashtra India. *Applied Water Science,* 7: 861–871. https://doi.org/10.1007/s13201-015-0298-7.

Pant, N., Dubey, R.K., Bhatt, A., Rai, S.P., Semwal, P. and Mishra, S. (2020) Soil erosion and flood hazard zonation using morphometric and morphotectonic parameters in Upper Alaknanda river basin. *Natural Hazards,* 103: 3263–3301.

Prabhakaran, A. and Jawahar Raj, N. (2018) Drainage morphometric analysis for assessing form and processes of the watersheds of Pachamalai hills and its adjoinings, Central Tamil Nadu, India. *Applied Water Science,* 8(1): 31. https://doi.org/10.1007/s13201-018-0646-5

Punithavathi, J., Tamilenthi, S. and Baskaran, R. (2011) Geologic and geomorphologic investigation of Cauvery River basin in Thanjavur District, Tamil Nadu, India using spatial technology. *Archives of Applied Science Research,* 3(3): 358–366.

Ramkumar, M., Santosh, M., Rahaman, S. M. A., Balasundareshwaran, A., Balasubramani, K., Mathew, M. J., Sautter, B., Siddiqui, N., Usha, K. P. and Sreerhishya, K. (2019) Tectono-morphological evolution of the Kaveri, Vaigai, and Thamirabarani River basins: Implications on timing, stratigraphic markers, relative roles of intrinsic and extrinsic factors, and transience of Southern Indian landscape. *Geological Journal,* 54 (5): 2870–2911.

Rao, N.K., Latha, S. ., Kumar, A.P. and Krishna, H.M. (2010) Morphometric analysis of Gostani river basin in Andhra Pradesh State, India using spatial information technology. *International Journal of Geomatics and Geosciences*, 1(2): 179–187.

Rice, B.L. (2024) *Mysore and Coorg. A Gazetteer Compiled for the Government of India.* Reprint of the original, first published in 1876, volume III,1st edition, Verlag publisher, Frankfurt, Deutschland: 427p.

Santosh, M., Yang, Q.Y., Shaji, E., Tsunogae, T., Mohan, M.R. and Satyanarayanan, M. (2015) An exotic Mesoarchean microcontinent: the Coorg block, southern India. *Gondwana Research,* 27(1): 165–195.

Schumm, S.A. (1956). Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. *Geological Society of America Bulletin,* 67 (5): 597–646.

Sharma, A. and Rajamani, V. (2000) Weathering of gneissic rocks in the upper reaches of Kaveri river, south India: implications to neotectonics of the region. *Chemical Geology,* 166(3-4): 203–223.

Sharma, A. and Rajamani, V. (2001) Weathering of Charnockites and sediment production in the catchment area of the Kaveri River, southern India. *Sedimentary Geology,* 143(1-2): 169–184.

Smith, K.G. (1950) Standards for grading texture of erosional topography. *American Journal of Science,* 248(9): 655–668.

Sreedevi, P.D., Subrahmanyam, K. and Ahmed, S. (2005) The significance of morphometric analysis for obtaining groundwater potential zones in a structurally controlled terrain. *Environmental Geology*, 47: 412–420.

Sreedevi, P.D., Sreekanth, P.D., Khan, H.H. and Ahmed, S. (2013) Drainage morphometry and its influence on hydrology in an semi-arid region: using SRTM data and GIS. *Environmental Earth Sciences,* 70: 839–848.

Sreelash, K., Mathew, M.M., Nisha, N., Arulbalaji, P., Bindu, A.G. and Sharma, R.K. (2020) Changes in the Hydrological Characteristics of Kaveri River draining the eastern side of southern Western Ghats, India. *International Journal of River Basin Management,* 18(2): 153–166.

Strahler, A.N. (1956) Quantitative slope analysis. Geological Society of *America Bulletin,* 67(5): 571–596.

Strahler, A.N. (1964) Quantitative geomorphology of drainage basin and channel networks. In Chow, In: Chow, V. (ed), *Handbook of Applied Hydrology,* McGraw Hill, New York: 439–476.

Swaminath, J. and Ramakrishnan M. (1981) Early Precambrian Supracrustals of Southern Karnataka., *Geological Survey of India*

Memoir, 112: 350p.

Taylor, B.E., Wheeler, M.C. and Nordstrom, D.K. (1984) Stable isotope geochemistry of acid mine drainage: Experimental oxidation of pyrite. *Geochimica et Cosmochimica Acta,* 48(12): 2669–2678.

Thakuriah, G. (2021) Morphometric Analysis of Kiling River Basin, North East India Using Geospatial Tools. *Journal of Indian Geomorphology,* 9: 44–55.

Thangaraj, K. and Karthikeyan, S. (2022) Application of remote sensing and GIS in floodwater harvesting for groundwater development in the Upper Delta of Kaveri River Basin, Southern India. In *Water Resources Management and Sustainability,* Springer: 257–280.

Thomas, J., Joseph, S., and Thrivikramji, K. P. (2015) Hydrochemical variations of a tropical mountain river system in a rain shadow region of the southern Western Ghats, Kerala, India. *Applied Geochemistry,* 63: 456–471.Bhavana N.

Umrikar, B.N. (2016) Morphometric analysis of Andhale watershed, Taluka Mulshi, District Pune, India. *Applied Water Science,* 7: 2231–2243. https://doi.org/10.1007/s13201-016-0390-7.

Vaidyanadhan, R. (1971) Evolution of the drainage of Kaveri in South India. Journal of the *Geological Society of India,* 12(1): 14–23.

Waikar, M.L. and Nilawar, A.P. (2014) Morphometric analysis of a drainage basin using geographical information system: a case study. *International Journal of Multidisciplinary and Current Research,* 2: 179–184.

Walcott, R.C. and Summerfield, M.A. (2008) Scale dependence of hypsometric integrals: an analysis of southeast African basins. *Geomorphology,* 96(1-2): 174–186.

Date received: 07 May 2024
Date accepted after revision: 28 July 2024