Geospatial Analysis of Kurumanpuzha Sub Watershed in the Chaliyar River Basin: A Remote Sensing and GIS Approach for Geomorphological Assessment

Abstract

Aims: This study aimed to determine geomorphological characteristics of Kurumanpuzha sub-watershed for understanding its hydrological behaviour, erosion susceptibility and geological characteristics.

Study design: Morphometric analysis of Kurumanpuzha sub-watershed was carried out using remote sensing and Geographic Information System (GIS) which is pivotal for sustainable resource management.

Place and duration of study: This study was conducted at Kelappaji College of Agricultural Engineering and Technology, Tavanur, Malappuram, Kerala during 2020-2021.

Methodology: The geomorphological characteristics of Kurumanpuzha sub-watershed were determined using GIS offering precise terrain insights to guide water resource planning, erosion control, infrastructure development and ecological conservation. Morphometric parameters were assessed based on linear, areal, and relief characteristics. USGS Earth Explorer platform was employed to download satellite images from multiple sources, including ISRO Resourcesat, Landsat, Sentinel, RADAR, and others. These images were then used to develop a Land Use Land Cover (LULC) map as well as other maps of the study area.

Results: The sub-watershed had a dendritic drainage pattern with a mean bifurcation ratio of 2.05, indicating easier flood management due to longer durations of low peak flows. The analysis revealed fine drainage, indicating a prevalence of soft rocks prone to erosion. The watershed had high relief and steep slopes, characterized by hills, breaks, and low mountains. The hypsometric curve indicated an equilibrium stage of geomorphic evolution. Morphometric parameters were grouped into three clusters at the sub-watershed level, demonstrating spatial variability. Forest/dense vegetation were the dominant land use, followed by rubber plantations and scrubland.

Conclusion: The findings of this study contribute to understanding of the hydrological behaviour, erosion susceptibility and geological characteristics of Kurumanpuzha sub-watershed. It is useful for effective watershed management, erosion control and informed decision-making in land use planning and engineering projects.

Keywords: GIS, Morphometric Analysis, Land Use Land Cover, Hypsometric Integral, Digital Elevation Model

1. Introduction

The Kerala state in India boasts a distinctive geographical composition, wedged between the Arabian Sea and the western ghats. With the majority of its land categorized as midland or highland and an annual rainfall of around 3000 mm, the region is susceptible to natural perils such as landslides, flooding, and tsunamis. Notably, studies like (**Sreedevi et al., 2009)** and (**Muluneh and Mamo, 2014)** have employed remote sensing and GIS techniques to analyse the morphometric attributes of watersheds, illustrating their profound impacts on hydrology and morphology. Such investigations provide crucial insights for watershed management, rainwater harvesting and planning. Morphometric analysis offers the opportunities to prioritize sub watersheds through evaluation of various linear and areal characteristics within the watershed **(Gautam et al., 2021).**

(Chandrashekhar et al., 2015) extended this approach to reservoir catchments in the Arkavati River, Karnataka. By utilizing high-resolution satellite data and GIS, they gained valuable knowledge about landforms, soil erosion, drainage, and groundwater potentials. Similarly, **(Soni, 2017)** scrutinized the Chakrar watershed in India, uncovering its mature geomorphic stage and low vulnerability to flooding and erosion. (**Kabite and Gessesse, 2018)** characterized Ethiopia's Dhidhessa river basin, revealing extensive stream networks, basin elongation, and diverse hydrological behaviours. This synthesis of morphometric analysis with geospatial tools proves indispensable in understanding the topographic features and hydrological dynamics of watersheds **(Shiono et al., 2002).** Remote sensing and GIS not only enable comprehensive assessments but also lay the foundation for effective drainage basin management strategies, safeguarding against various environmental challenges **(Zhang, et al., 2009).** The present study focuses on assessing the hydro-geomorphological characteristics of the Kurumanpuzha sub-watershed within the Chaliyar River basin. This analysis is conducted using remote sensing and Geographic Information System (GIS) techniques, which offer valuable tools for comprehensively understanding and managing the environment. The study is important because it provides essential information for effective watershed management, erosion control, and informed decision-making in land use planning and engineering projects within the Kurumanpuzha sub-watershed.

2. Material and Methods

2.1 Study area

The Kurumanpuzha sub-watershed in Chaliyar river basin covers 3.55% of the catchment area, with an area of 103.6 km^2 and a length of 19.084 km. Its undulating topography spans forested hills to coastal flats. The region experiences a humid tropical climate, with average annual rainfall of 2419 mm and a mean temperature of 27.8°C. Soils are well-drained, ranging from pale brown to dark yellowish-brown, supporting crops like coconut, rubber, areca nut, cashew, pepper, paddy and bananas. The location map of study area is shown in **Fig. 1.**

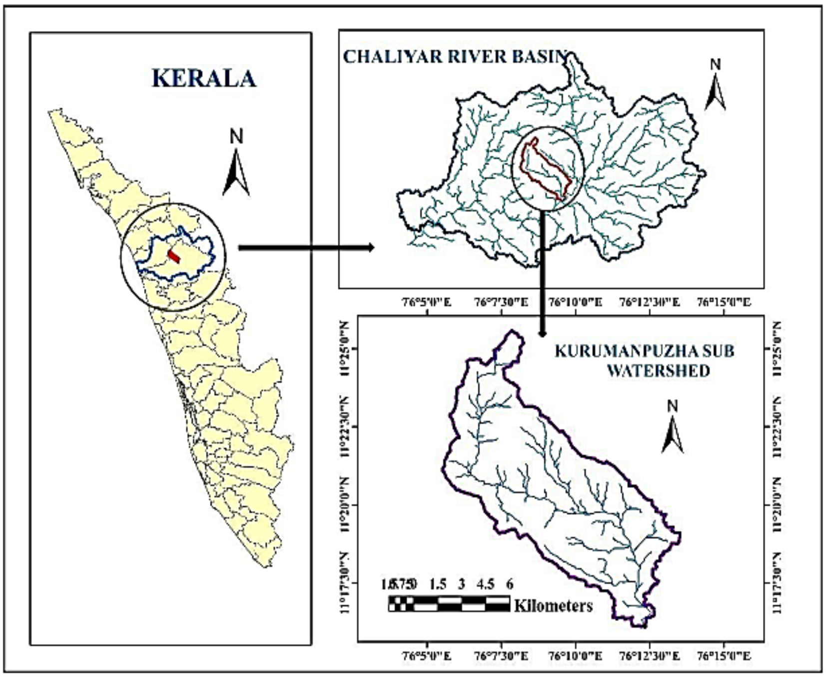


Fig. 1 Location map of the study area

2.2 Tools and software used

ArcGIS 10.2 and ERDAS IMAGINE software played crucial roles in the study, providing the necessary tools for geospatial analysis, hydrological analysis and image processing. These software tools were instrumental in handling and analysing the geographical data, enabling to derive meaningful insights for the study.

2.3 Data collection

The USGS Earth Explorer platform was employed to download satellite images (source year: 2019) from multiple sources, including ISRO Resourcesat, Landsat, Sentinel and RADAR. These images were then used to develop a land use land cover (LULC) map of the study area. The Earth Explorer system provided an interactive user interface, allowing for customized searches based on location coordinates, predefined areas, shape files, and specific data ranges. Additionally, it offered the ability to filter for cloud cover in the acquired imagery. Bhuvan, an Indian Geo-platform developed by ISRO, was utilized to download CartoSat-DEM satellite imageries with a resolution of 30 m. Two tiles of images with minimal cloud cover were selected to cover the entire research region. The downloaded images were further processed, including pan-sharpening, using ArcGIS software. Overall, these tools and techniques facilitated the gathering of satellite images, DEM, soil data, and rainfall data, enabling comprehensive analysis and extraction of valuable information for the study **(Bayramov et al., 2013).** Elevation adjustments using ArcGIS's Fill tool resolved terrain flow gaps. Flow direction was determined with the Flow Direction tool on the filled DEM. Flow accumulation gauged surface flow in each cell. Watershed boundaries were defined using ArcGIS Hydrology tools. Aspect was deduced from a slope raster derived from the DEM. Slope map assessed catchment morphology. Landsat 8 imagery was pre-processed in ERDAS IMAGINE 2015 for LULC mapping, involving rectification, stacking, enhancement, and extraction. Unsupervised classification grouped imagery into 150 classes. Validation used aerial, Google images, and ground truth data for training sites **(Alexandridis et al., 2015).**

2.4 Hydro geomorphological parameters of the watershed

Hydro-geomorphological characterization plays a crucial role in systematically describing the various aspects of watershed geometry and stream channel systems. It is essential to consider several key measurements, including linear, areal, and relief aspects. Stream order classification is a valuable tool for categorizing stream ranks and understanding their sequence and contribution. Stream number, which follows an inverse geometric sequence with order, is an important aspect to consider. Determining stream length using ArcGIS's flow length tool provides insights into drainage system traits, and stream length ratios can help highlight the maturity of a watershed, increasing from lower to higher order streams.

Bifurcation ratio (Rb), a dimensionless measure, was employed to divide stream segments between successive orders, as proposed by **Schumn (1956).** Strahler's modification to Horton's ordering system offered flexibility in classifying streams. These parameters were indispensable for conducting hydrological analyses and instrumental in effective resource planning and management.

Watershed characteristics offered valuable insights into the field of hydrology. Parameters such as drainage area (A) and form factor (Rf) played a significant role in revealing runoff behaviour and basin shape, as initially described by **Horton (1945).** Drainage density (Dd) was a useful metric for indicating channel spacing, which, in turn, affects infiltration and surface overflow. Stream frequency (F) reflected the impact of permeability on runoff. Circulatory ratio (Rc) and elongation ratio (Re) provided important information about basin circularity and shape, following the work of **Miller (1953) and Schumn (1956).** Metrics like compactness coefficient (Cc) and drainage texture (Dt) aided in understanding runoff patterns, while the length of overland flow (Lg) played a significant role in shaping basin development. Collectively, these parameters served to unravel the intricacies of hydrology and offered essential insights into how water navigates diverse landscapes.

The study employed a range of geomorphological parameters to assess the influence of watershed characteristics on runoff and erosion susceptibility. These parameters include maximum watershed relief (H) for quantifying elevation variance, relative relief (RR) for indicating basin steepness, relief ratio (Rr) to highlight sharpness, ruggedness number (Rn) to showcase roughness, and time of concentration (Tc) for denoting runoff duration, as outlined by **Melton (1957) and Strahler (1964).** The analysis involved plotting a hypsometric curve, linking cross-sectional area and elevation, with the hypsometric integral (HI) was being used to understand geomorphology.

These insights were pivotal in managing floods and engineering projects, as they had a direct impact on runoff patterns, flood occurrence, and erosion control. The study's evaluation of linear, areal, and relief aspects provided valuable clarity on their roles in peak flow and erosion, offering essential information for making informed decisions regarding watershed management and engineering projects.

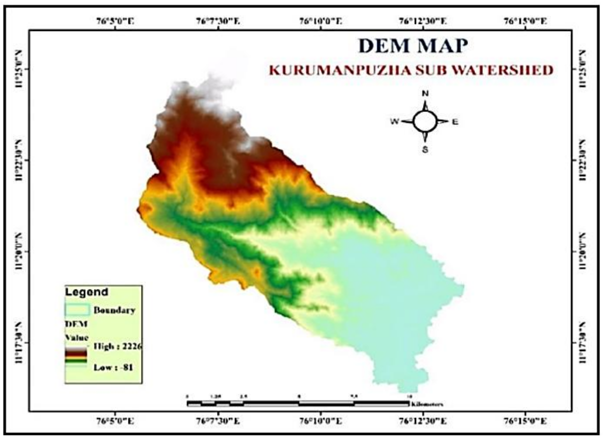
3. Results and Discussion

3.1 Digital Elevation Model (DEM)

The Kurumanpuzha sub-watershed was delineated using ArcGIS. It involved DEM analysis, Fill, Flow Direction, Flow Accumulation and boundary delineation from the outlet point at Conolly plot near Nilambur. The watershed covers 10,359.05 hectares, with dimensions of 19.19 km length, 9.2 km width and a 60.63 km perimeter. The DEM map of watershed is shown in **Fig. 2.**

3.2 Flow direction and flow accumulation

The flow direction was obtained by using the DEM file and Spatial Analyst Tool in the Hydrology section of ArcGIS software. Flow accumulation map was generated from the 'Flow Direction' using the Spatial Analyst Tool. The result of the flow accumulation raster was in the range of 0 to 110474. The black portion represents the lesser flow accumulation values while the white portion represents the higher flow accumulation values, as shown in **Fig. 3.** The major flow accumulation was directed towards the southern sides of the watershed with lesser accumulation in the northern direction, and finally, the flow connects to the outlet. The watershed outlet is directed to the Chaliyar River, located at the south end of the watershed.



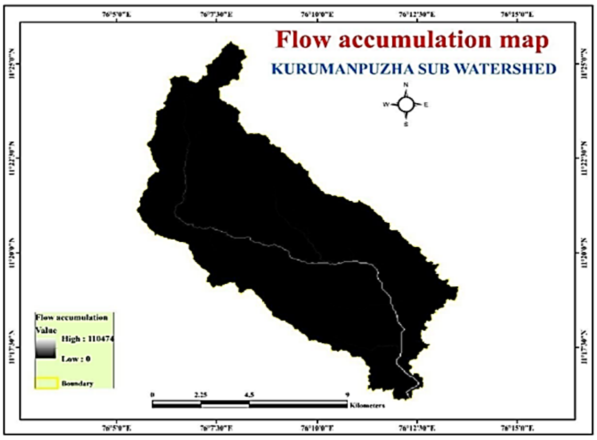
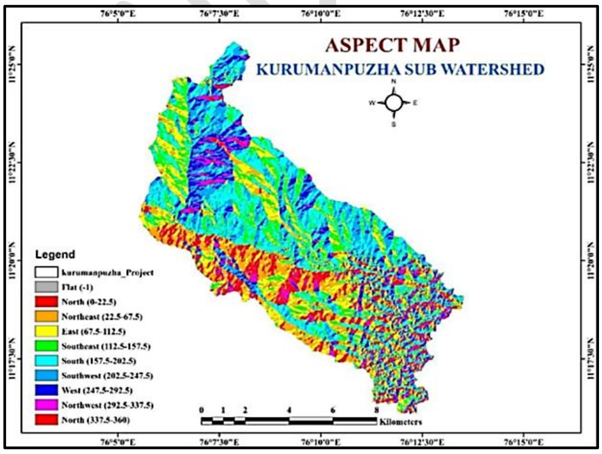


Fig. 2 DEM map of the watershed

Fig. 3 Flow accumulation map

3.3 Aspect

Aspect maps given the observer a sense of the direction in which various slopes derived from a DEM lie. The aspect map value -1 denoted a slope of zero, i.e., flat terrain. The value of slope direction ranged from 0 to 22.5, indicating that the slope is to the north. Similarly, other values ranging from 22.5 to 67.5 indicate a slope to the north-east, while values ranging from 67.5 to 112.5 indicated a slope to the east. Similarly, slope directions of 112.5 to 157.5, 157.5 to 202.5, 202.5 to 247.5, 247.5 to 292.5, 292.5 to 337.5, and 337.5 to 360 indicated direction towards the South East, South, South West, West, North West, and North. The majority of the flow in the Kurumanpuzha sub-watershed was south. The aspect map and drainage network map of watershed are shown in **Fig. 4 and Fig. 5,** respectively.



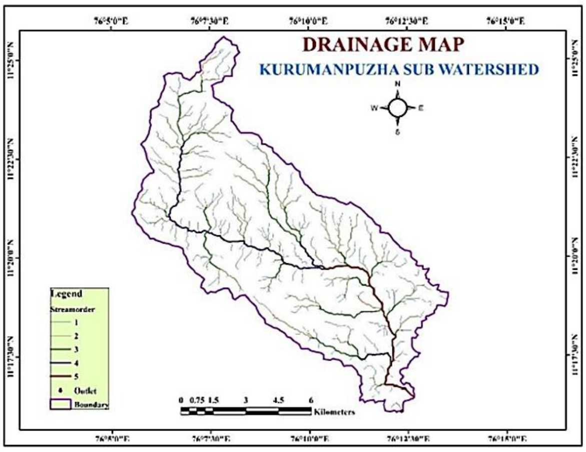


Fig. 4 Aspect map of sub watershed

Fig. 5 Drainage network map

3.4 Land Use Land Cover (LULC)

The water bodies, Forest/dense vegetation, rubber, coconut/areca nut, cropland, scrubland, and bare land are the type of land uses identified in the study area. Forest/dense vegetated area (56.46%) were estimated as the major land use with the Rubber plantation (20.06%). Rubber, coconut and areca nut were identified as the major crops in the study area. The field views of different land uses in the study area and land use land cover map of watershed are shown in **Fig. 6 and Fig. 7,** respectively.

Fig. 6 Field photographs of different land uses of the study area

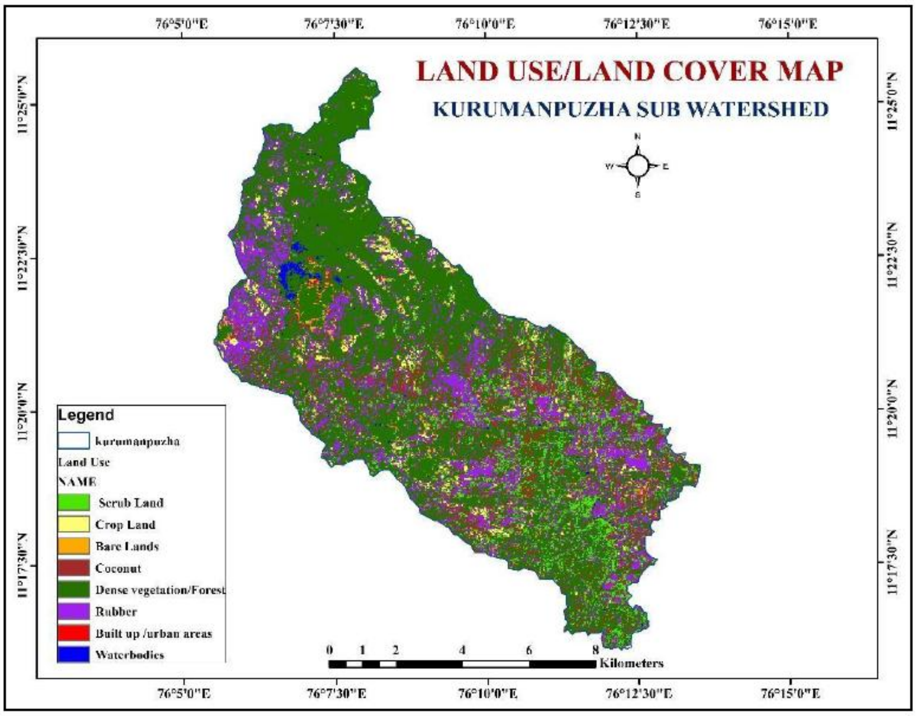


Fig. 7 Land Use Land Cover (LULC) map of the study area

3.5 Geomorphological characteristics of Kurumanpuzha sub watershed

Morphological characteristics give the basis for analysing the drainage basin slope, rock hardness differences, structural control, and watershed geology. The geomorphologic study of the drainage area aimed to collect precise data on measurable features of the stream network. By using the drainage map of the study area, morphometric analysis and basin boundary values of various morphometric parameters were measured.

3.5.1 Linear aspects of the drainage network

The study area has a 5th order stream and a dendritic drainage pattern according to the output. The maximum watershed length and the width were 19.19 and 9.20 km, respectively. The number of first, second, third, fourth and fifth order streams were 294, 137, 74, 59 and 20, respectively. According to Horton, as stream order increases, stream number decreases **(Thomas et al., 2018).** In this study, the results of stream number support Horton's law. The total length of 1st, 2nd, 3rd, 4th and 5th order streams are 120.744, 62.687, 29.48, 17.22 and 10.26 km, respectively. The stream lengths of different orders and their relative mean stream lengths were calculated by digitising the stream networks in ArcGIS software. **Table 1** shows stream order and mean stream length of sub watershed.

Table 1 Stream order and mean stream length of Kurumanpuzha sub watershed

Parameters	**Stream order**					**Total**
	I	II	III	IV	V	
No of streams	294	137	74	59	20	584
Total stream length, km	120.74	62.68	29.48	17.22	10.26	240.44
Mean stream length, km	0.842	1.808	3.348	4.200	12.391	22.589

Stream length ratio (R_L)

The stream length ratio (R_L) values for second to first, third to second, fourth to third and fifth to fourth-order streams were obtained to be 2.147, 1.851, 1.254 and 2.95, respectively **(Table 2).** Changes in slope and topography can be compared to changes in stream length ratio. The length ratio in the study area fell from third to fourth order, indicating that the study area is in the late-stage of its geomorphic development. On the other hand, the fourth to fifth-order stream length ratio increases compared to the fourth to third order, showing that the watershed has reached its mature geographic stage.

Table 2 Stream length ratio of Kurumanpuzha sub watershed

Stream order	**Mean stream length, km**	**Stream length ratio (R_L)**
I	0.842	-
II	1.808	2.147
III	3.348	1.851
IV	4.200	1.254
V	12.391	2.95

For the Kurumanpuzha sub watershed, the number of streams in each order was counted and recorded. The logarithm of the number of streams versus the order of the streams is plotted in **Fig 8.** The graph shows a straight line following Horton's law, which states that the number of stream segments in a drainage system has a linear relationship with minimal variance. As a result, in geometric progression, as stream order increases, the number of streams decreases. A graph showing the relationship between total stream length and stream order (U) was plotted **(Fig 9).** To study the geometric property of the correlation, the logarithm of total stream length was plotted as the ordinate and the stream order (U) as the abscissa on the arithmetic scale. In the first order, the total length of the stream segments was long. As the stream order increases, stream segments become shorter. It shows a nearly straight line fit with the logarithm of cumulative stream length as the ordinate and the stream order as the abscissa. The straight-line fit indicates that the total stream length to order ratio remains constant as the basin order increases. 3rd and 4th order stream of Kurumanpuzha sub watershed are shown **in Fig. 10 and Fig. 11**, respectively.

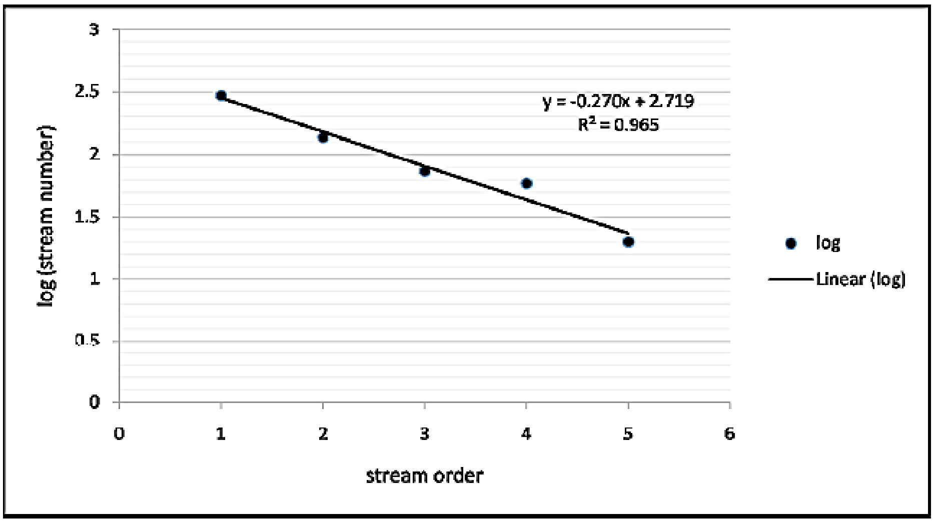


Fig. 8 Regression plot of logarithm of stream number versus stream order

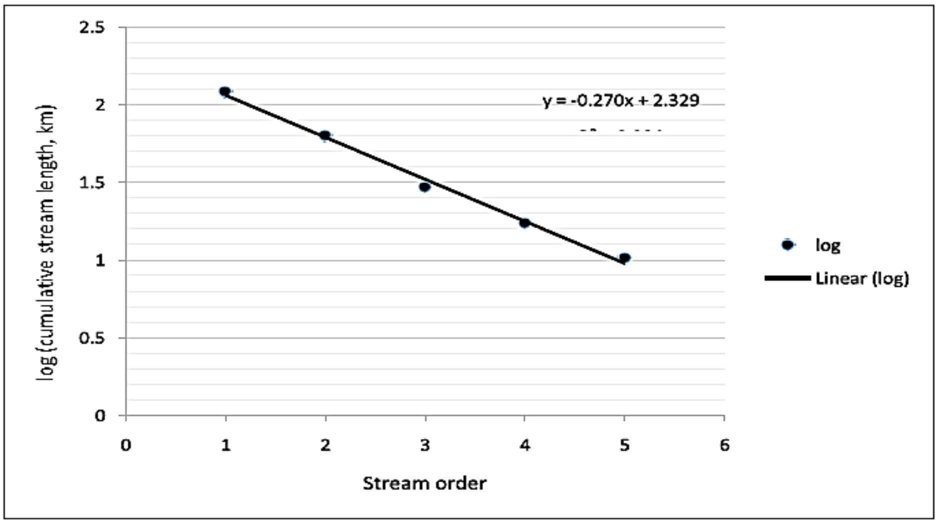


Fig. 9 Regression plot of the logarithm of total stream length and stream order

Fig. 10 3rd order stream of sub watershed **Fig. 11 4th order stream of sub watershed**

Bifurcation Ratio (R_b)

The bifurcation ratio (R_b) is another significant aspect of the drainage network that represents the watershed's geological and tectonic properties. The R_b values from 1st to 2nd, 2nd to 3rd, 3rd to 4th, and 4th to 5th order streams were 2.14, 1.85, 1.25 and 2.95, respectively, and the mean bifurcation ratio was 2.05 **(Table 3).** A smaller bifurcation ratio reflected that the watershed has experienced less structural disturbance, and there is no change in the drainage pattern because of the structural disturbance **(Nag and Lahiri, 2011).**

Table 3 Bifurcation ratio of Kurumanpuzha sub watershed

Stream order	No of stream	Bifurcation ration(Rb)
I	294	2.14
II	137	1.85
III	74	1.25
IV	59	2.95
V	20	-
Mean	-	2.05

3.5.2 Areal aspects of drainage network

The areal aspects of a drainage network were systematically measured in this study. Various parameters such as watershed, form factor, drainage density, drainage texture, stream frequency, circulatory ratio, elongation ratio, compactness coefficient, texture ratio, and length of overland flows were analysed. The form factor (0.284) indicates that the watershed is elongated, which can lead to longer flood flows that are easier to manage. The compactness coefficient (0.585) suggests a lower erosion risk for the entire watershed. The drainage density (2.392 km km^{-2}) revealed the closeness of channel spacing and overall channel length. The high drainage texture (9.632 km^{-1}) indicated fine drainage texture, moderate infiltration rates, and the dominance of impermeable soft rock. The moderate stream frequency (5.637 km^{-2}) suggested good vegetation cover and permeable subsurface material. The length of overland flow (0.209 km) indicated predominant channel flow and increased stream erosion due to high drainage density. **Table 4** shows Areal aspects of Kurumanpuzha sub watershed.

Table 4 Areal aspects of Kurumanpuzha sub watershed

S. N.	Parameters	Value
1	Watershed area (A), ha	10359.053
2	Watershed width (B), km	9.200
3	Form factor (Rf)	0.281
4	Drainage density (Dd), km km^{-2}	2.392
5	Drainage texture (Dt), km^{-1}	9.632
6	Stream frequency (F), km^{-2}	5.637
7	Circularity ratio (Rc)	0.353
8	Elongation ratio (Re)	0.598
9	Compactness coefficient (Cc)	0.585
10	Texture ratio (Rt)	4.849
11	Length of overland flow (Lg), km	0.209

3.5.3 Relief aspects of drainage network

The relief aspects of the Kuruvanpuzha Sub Watershed were assessed in this study. The maximum watershed relief (H) was determined to be 2307 m, indicating a high relief value. The relative relief (R) was found to be 3.82%, while the relief ratio (Rr) was calculated as 0.12. The ruggedness number (Rn) was determined to be 5.51, suggesting the presence of higher elevated areas in the watershed. The time of concentration (Tc) was estimated to be 8.89 minutes, representing the travel time for water from the farthest reaches of the watershed to its outlet **(Sreedevi et al., 2013).** These findings highlight the significant influence of relief aspects on watershed characteristics and runoff generation. Relief aspects of drainage network are shown in **Table 5.**

Table 5 Relief aspects of drainage network

S. N.	Relief parameters	Value
1	Maximum watershed relief (H), m	2307
2	Relative relief (R_R)	3.82
3	Relief ratio (R_r)	0.12
4	Ruggedness number (R_n)	5.51
5	Time of concentration (Tc), min	8.89

3.5.4 Hypsometric integral

The hypsometric curves have been plotted between the cumulative percentage of the surface areas with respect to the elevation of the study area by using DEM in arc GIS. The hypsometric integral (HI) was estimated using the elevation relief ratio method. The HI values of the Watershed were about 0.48, indicating that elevation was in equilibrium stages. **Fig. 12** shows the hypsometric curve of the Kurumanpuzha sub-watershed.

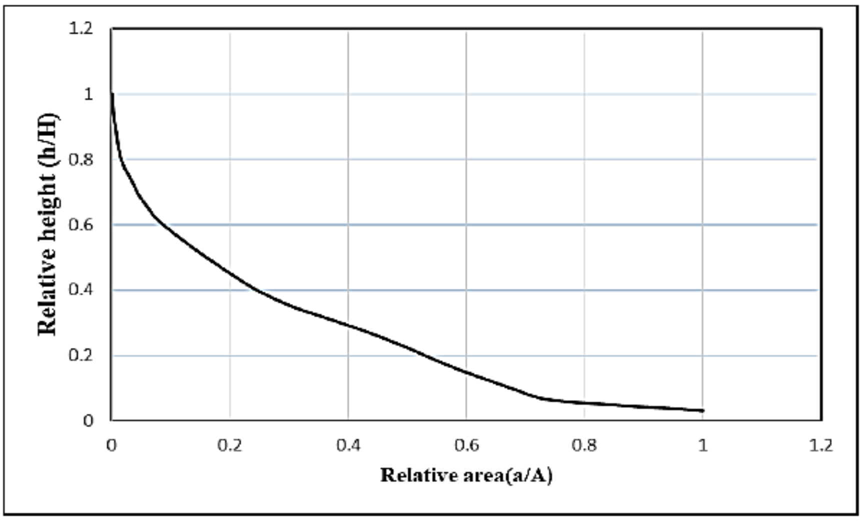


Fig. 12 Hypsometric curve of Kurumanpuzha sub watershed

3.6 Conclusion

This study conducted a thorough examination of the Kurumanpuzha sub-watershed's geomorphological features, shedding light on its hydrological and erosional traits. It harnessed a range of parameters derived from Digital Elevation Model (DEM) data and employed spatial analysis techniques to offer a holistic assessment of the watershed's attributes. In terms of the drainage network, it exhibited a branching, tree-like pattern with a 5th order stream, fitting the classic dendritic pattern observed in many watersheds. Morphometric analysis disclosed an intriguing trend: as the stream order increased, the number of streams decreased, a pattern consistent with Horton's law. These findings provide insights into the watershed's evolutionary stage. Stream length ratios hinted at a relatively advanced stage of geomorphic development, while bifurcation ratios suggested stable structural conditions. The spatial characteristics of the drainage network were equally revealing. The watershed displayed an elongated shape, with moderate vegetation cover. The compactness coefficient indicated a lower risk of erosion, and drainage density and texture values pointed to the predominance of impermeable soft rock and a fine drainage texture, which can impact water flow and infiltration. Relief-related aspects highlighted significant variations in the landscape. The watershed exhibited elevated terrain, as indicated by high values for maximum relief, relative relief, and ruggedness number. These metrics underscored the presence of varied topography within the sub-watershed. The hypsometric integral, which indicates the balance in elevation distribution, suggested a state of equilibrium within the elevation ranges across the watershed. Therefore, these findings collectively contribute to a comprehensive understanding of the Kurumanpuzha sub-watershed's behavior in terms of hydrology, erosion susceptibility, and geological characteristics. This knowledge is invaluable for effective watershed management, erosion mitigation strategies and making informed decisions regarding land use planning and engineering projects in the area.

4. References

Alexandridis TK, Sotiropoulou AM, Bilas G, Karapetsas N and Silleos NG. The Effects of Seasonality in Estimating the C- Factor of Soil Erosion Studies. Land Degradation and Development. 2015; 26(6): 596-603.

Bayramov E, Buchroithner MF and McGurty E. Differences of MMF and USLE Models for Soil Loss Prediction along BTC and SCP Pipelines. Journal of Pipeline Syst. Engineering Practice. 2013; 4(1): 81-96.

Chandrashekar H, Lokesh KV, Sameena M and Ranganna G. GIS Based Morphometric Analysis of Two Reservoir Catchments of Arkavati River, Ramanagaram District, Karnataka. Aquatic Proceedings. 2015; 4: 1345-1353.

Gautam, VK, Kothari M, Singh PK, Bhakar SR and Yadav KK. Determination of Geomorphological Characteristics of Jakham River Basin using GIS Technique. Indian Journal of Ecology. 2021; 48(6): 1627-1634.

Horton RE. Erosional Development of Streams and Their Drainage Basins Hydro Physical Approach to Quantitative Morphology. 1945; 275-370.

Kabite G and Gessesse B. Hydro-Geomorphological Characterization of Dhidhessa River Basin, Ethiopia. International Soil and Water Conservation Resources. 2018; 6(2): 175-183.

Miller VC. A Quantitative Geomorphic Study on Drainage Basin Characteristics in the Clinch Mountain Area, Virginia and Tennessee, Project NR 389-042, Technical Report 3. Columbia University, New York. 1953.

Melton MA. An Analysis of the Relations among Elements of Climate, Surface, Properties and Geomorphology. Project NR 389- 042 Technical Report 11. Columbia University, Department of Geology, ONR, Geography Branch, New York. 1957.

Muluneh T and Mamo W. Morphometric Analysis of Didessa River Catchment in Blue Nile Basin, Western Ethiopia. Sci. Technol. Arts Res. J. 2014; 3(3): 191-197.

Nag SK and Lahiri A. Morphometric Analysis of Dwarakeswar Watershed, Bankura District, West Bengal, India, using Spatial Information Technology. International Journal of Water Resources and Environmental Engineering. 2011; 3(10): 212-219.

Schumm SA. Evolution of Drainage Systems and Slopes in Badlands at Port Amboy, New Jercy. Bulletin of Geological Society. 1956; 67: 597-646.

Shiono T, Kamimura KI, Okushima S and Fukumoto M. Soil Loss Estimation on a Local Scale for Soil Conservation Planning. Japan Agric. Res. Quart: JARQ. 2002; 36(3): 157-161.

Soni, S. 2017. Assessment of morphometric characteristics of Chakrar watershed in Madhya Pradesh India using geospatial technique. *App. Water Sci*., 7(5): 2089-2102.

Sreedevi PD, Sreekanth PD, Khan HH and Ahmed S. Drainage Morphometry and Its influence on Hydrology in an Semi-Arid Region: Using SRTM Data and GIS. Environmental Earth Sciences. 2013; 70(2): 839-848.

Strahler AN. Part II: Quantitative Geomorphology of Drainage Basins and Channel Networks. . Handbook of Applied Hydrologymcgraw-Hill, New York. 1964; 4-39.

Thomas J, Joseph S and Thrivikramji KP. Assessment of Soil Erosion in a Monsoon Dominated Mountain River Basin in India using RUSLE-SDR and AHP. Hydrol. Sci. J. 2018; 63(4): 542-560.

Zhang Y, Degroote J, Wolter C and Sugumaran R. Integration of Modified Universal Soil Loss Equation (MUSLE) into a GIS Framework to Assess Soil Erosion Risk. *Land Degradation and Development.* 2009; 20(1): 84-91.