Evaluation and Analysis of Drainage Morphometry of Kumari River Basin in Chhotanagpur Plateau with the help of Geospatial Techniques

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Abstract : *This study presents a comprehensive morphometric and geomorphological analysis of the Kumari River Basin, located within the Chhotanagpur Plateau, using advanced geospatial techniques. The research employs Survey of India topographic maps and Landsat OLI 8 satellite imagery to extract linear, areal, and relief parameters through GIS-based analysis. Stream ordering, bifurcation ratios, drainage density, and hypsometric evaluations are used to interpret the geomorphic structure and developmental stage of the basin. The calculated bifurcation ratios (ranging from 3 to 4) suggest moderate structural control on drainage evolution, while a hypsometric integral value of 0.50 reflects a mature geomorphic stage characterised by balanced erosional and depositional processes. The basin exhibits moderately dissected terrain with peneplain surfaces dominating the landscape, indicative of an extensive denudational history. The integration of morphometric indices with geomorphological mapping offers critical insights into terrain evolution, hydrological processes, and the influence of tectonic activity. These findings are significant for regional watershed planning, land-use strategies, and sustainable management practices in the Kumari River Basin.*

Key words: *Drainage Morphometry, Geospatial Techniques, Hypsometric Analysis, Watershed Management*

Introduction

A drainage basin is a part of land drained by a river and its tributaries, bounded by different watersheds. The relationship between the parts of the system can be analyzed in teams of stream order, etc. Such a method constitutes the basis of drainage basin Morphometry. Drainage morphometry is defined as a measurement of linear, areal, and relief characteristics of any drainage basin (Clarke 1966). Drainage morphometry was first initiated by Horton (1932). The drainage morphometric characteristics are important to understanding the underlying structure, geomorphological formations, and hydrological characteristics of any basin (Morisawa 1985). The relationship between drainage morphometric parameters and their underlying geology, geomorphology, and hydrological characteristics is established through the work of different geologists and geomorphologists (Strahler 1952; Chorley et al. 1985). It also plays an important role in characterizing soil erosion, flood conditions, and geomorphological processes (Chavare and Potdar 2014). The evolutionary history of any basin can be best understood through the

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implication of different relief morphometric measures of the drainage basin (Sharma and Sarma 2013). The different morphometric characteristics, like linear parameters (stream order, stream number, bifurcation ratio, strength length, mean stream length), areal or basin parameters (drainage density, drainage frequency), and relief parameters (dissection index, hypsometric characteristics) are important for any river basin management. The hydrological and morphological behaviour of any basin can be best understood through the areal and relief morphometric parameters, respectively. Different fluvial processes with morphometric characteristics are well established (Chorley et al. 1985; Vittala et al. 2004). The geomorphological stages of evolution with their erosional characteristics can also be best understood through the different drainage morphometric parameters (Strahler 1952). It provides enormous ideas to identify the morphological, and hydrological problems and helps with related management procedures.

Aims and Objectives

The present study of investigation has set the following as its aim and fulfils the objectives:

- To examine the development of landforms of the Kumari River basin resulting from the varied litho–tectonic–structural differences. It is an important step for the analysis of the terrain pattern as the varied landforms of the watershed are the results of different structures, stages, and related geomorphic processes. It also relates to the analysis of the drainage characteristics with special reference to the varied meso and micro aspects of the Kumari River basin.
- To prepare a detailed geomorphological map of the Kumari River basin based on modern geospatial techniques.

Hypothesis

This research addresses three primary objectives that guide the investigation of geomorphological and land use dynamics in the Kumari River basin. The study aims to examine how different types of landforms develop across various courses of the Kumari River basin, establishing the relationship between fluvial geomorphology and landform evolution. Additionally, the research seeks to understand how the geomorphology of the area controls the evolution and distribution of various land use and land cover types under different landforms, providing insights into the spatial organization of human activities in relation to physical terrain. Finally, the study analyzes the impact of the Watershed Development Program on both land use patterns and geomorphic features within the Kumari River basin, evaluating the effectiveness of conservation interventions on landscape dynamics.

Methodology

For the present study the Survey of India's topographic sheets No.73I/4,73I/8,73I/12, 73I/16, 73J/1, 73J/5, 73J/6, 73J/9, and 73J/10 of 1: 50,000 scales were made use of. The digital data format from Landsat OLI 8 with a 30-meter spatial resolution with four spectral bands was used to meet

Table 1: Formula adopted for computation of morphometric parameters in Kumari Watershed

Morphometric Aspects	Parameters	Formula	References
Linear Aspect	Stream order (u)	Hierarchical rank	Strahler (1964)
	Stream no. (Nu)	Nu = number of streams of a particular order 'u'	Strahler (1964)
	Bifurcation ratio (Rb)	Rb = (Nu/Nu+1); Where, Nu = number of streams of a particular order 'u', Nu+1 = Number of streams of next higher order 'u+1'	Strahler (1964)
	Stream length (Lu)	Lu = total length of streams (km) of a particular order 'u'	Horton (1945)
	Mean stream length (Lum)	Lum = Lu/Nu; where, Lu = total length of streams (km) of a particular order 'u', Nu = total number of streams of a particular order 'u'	Horton (1945)
	Stream length ratio (Rl)	Rl = Lum/Lum+1; where, Lu = mean stream length of a particular order 'u', Lu+1 = mean stream length of next higher order 'u+1'	Horton (1945)
Areal Aspect	Drainage Density (Dd)	Dd = L/A; where, L = length of streams (km), A = Basin area (km)	Horton (1945)
	Stream frequency (Fs)	Fs = N/A; where, N = total number of streams of a given basin, A = total area of basin (km)	Horton (1945)
	Texture ratio (Rt)	Rt = Dd*Fs, where, Dd = drainage density (km/km), Fs =stream frequency (number/km)	Smith (1950)
	Form factor (Ff)	Ff = A/L2; where, A = area of the basin (km), L = basin length (km)	Horton (1945)
	Circularity ratio (Rc)	Rc =4<πA/P2; where, A= area of the basin (km), P = outer boundary of a drainage basin (km)	Strahler (1964)
	Elongation ratio (Re)	Re = P/<πL; P = outer boundary of a drainage basin (km), L = basin length (km)	Strahler (1964)
Relief Aspect	Relative relief (H)	H = R – r, where, R = highest relief, r = lowest relief	Schumm (1956)
	Absolute Relief	The maximum elevation of each unit area (m)	Dov Nir, 1957
	Dissection index (Di)	Di = H/R; H= relative relief (m), R= absolute relief (m) (max value)	Schumm (1956)
	Hypsometric analysis	E = (Mean elevation – Minimum elevation / Maximum elevation – Minimum elevation)	Strahler (1952)

Source: *Compiled by the author*

the requirements of the area under study. The Survey of India toposheets, and digital satellite images were geometrically rectified subset and merged using ERDAS Imagine software. The study area has been divided into eight sub-watersheds of Kumari River Basin. The sub-watersheds are Chaka Nadi, Totko Nadi, Jamuna Nadi, Sona Nadi, Nangasai Nadi, Hunuman Nadi, Jore Nala, Nangasai Nala. The digitization of watershed delineation and drainage order is carried out in ArcGIS10.8 software. Morphometric parameters under linear, areal, and relief are computed using standard methods and formulas i.e. Strahler (1964), Schumm (1956), Horton (1945), Smith (1950) (Table 1).

Study Area

The Kumari River basin is bounded by Latitude 22^0 05' N to 22^0 21' N and Longitude 87^0 51' E to 87^0 51' E. The total geographical area is 1901.86 km^2. The major basin area is situated in the Puruliya district of West Bengal, and the smaller part of the basin area is located in the East Singhbhum district of Jharkhand (Fig. 1). It originated from Ajodhya hill and flows from west to east up to Kangsabati River. Nangasai, Hanumata, Chaka, Totko, Sona, Jamuna, Jore Nala, and Nangasai Nala are the tributaries of the Kumari River (Ghosh et al. 2015; Ghosh and Jana 2017). It is located between the Kangsabati and the Subarnarekha rivers.

The Kumari drainage system covers a total area of 1901.76 km^2. It originates on the northwestern part of the Karma hills (725m); flowing to the southeast, it follows the northwest projection of Bamundiha Pahar (262m) to bend sharply southeastward along its eastern upland, forming Bamni upland (203m). In the upper part of its course, it has a rapid flow and brings down large quantities of silt. The bed of the river has an elevation of 450 m at the confluence of the one source stream. Thus, it has a total stream length of 49.8 km in the study area. Nangasai, Hanuman, Chaka, Totko, Sona, etc., are the tributaries of the Kumari River. It is located between the Kangsabati and the Subarnarekha rivers.

Linear Analysis of Kumari River Basin

Linear aspects of the basins are related to the channel patterns of the drainage network, wherein the topological characteristics of the stream segments in terms of open links of the network system (streams) are analyzed. The linear aspect includes the discussion and analysis of stream order, stream number, bifurcation ratio, stream lengths, length ratio, etc., showing the different components of a drainage basin.

Stream Ordering

The first step of drainage analysis is stream-ordering. The concept of Stream Order was first founded by Horton (1945), but it was modified by Strahler (1952). In the present study, the stream ordering of the Kumari River watershed has been done based on the proposed Hierarchical Rank method of Strahler (1964) using the SOI Toposheet in ArcGIS-10.8 software. According to

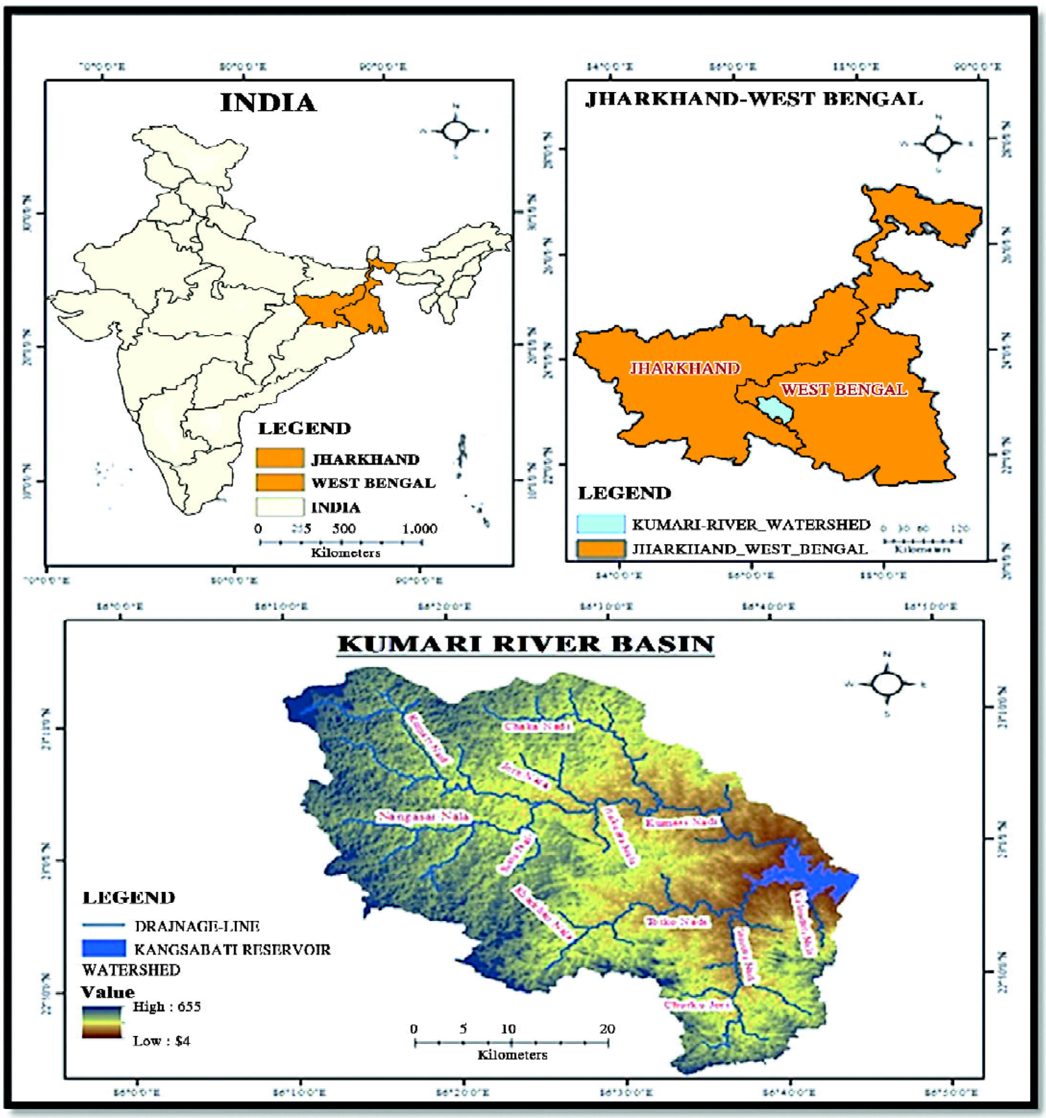

Fig. 1: Location Map of the Study Area

Source: Prepared by the author

Strahler, each finger-tip channel is designated as a segment of 1st order. When any two 1st-order segments are joined, a channel of the 2nd-order stream is produced, where two 2nd-order streams join a 3rd-order streams are produced, and so forth (Fig. 2).

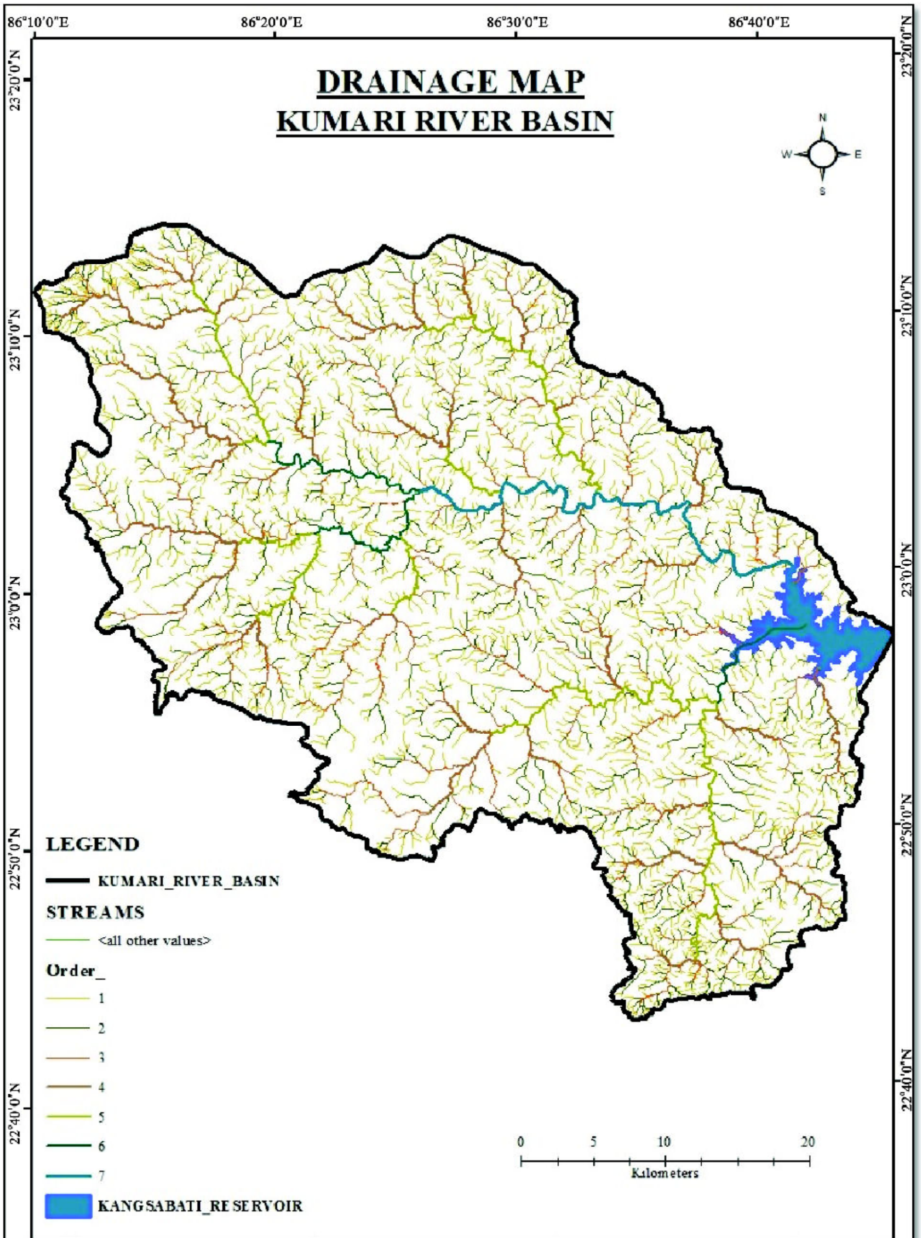

Fig. 2

Source: *Prepared by the Author based on Using SOI Toposheet*

In the present study, it is observed that (Table 2) the maximum drainage order is shown in the first-order stream. Stream order has decreased, whereas stream order has increased.

Table 2: Stream Order of Kumari Watershed

Stream Order	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**
Stream Number	3226	801	180	40	9	3	1

Source: *Prepared by the Author based on SOI Toposheet*

Stream Length

Stream length is the most significant parameter of the Morphometric analysis of watersheds. The length of the computed streams of different orders from the SOI Topo sheet has been calculated with the help of ArcGIS 10.4 software based on the proposed theory of Horton (1945). The stream length has been decreased with increasing stream order, which indicates that geometrical similarity is preserved generally in the watershed of increasing order. The value of the stream length of different stream orders of the Kumari River Basin is shown below.

Table 3: Total Stream Length of Kumari Watershed

Stream Order	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**
Stream Length (Km)	1818.12	757.17	435.45	199.88	126.15	36.67	49.86

Source: *Prepared by the author based on SOI Toposheet*

Mean Stream Length

Mean Stream length is a dimensional property revealing the characteristic size of components of a drainage network and its Contributing watershed surfaces (Strahler, 1964). The mean stream length of a given order is higher than the lower order and less than its next higher order. In the present study, the same process was followed in the Kumari River watershed that indicated the watershed controlled by lithology and structure. The mean stream length of the different order has been shown in Table 4.

Table 4: Mean Stream Length of Kumari Watershed

Stream Order	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**
Mean Stream Length (Km)	0.56	0.95	2.42	5.00	14.02	12.22	49.86

Source: Prepared by the author based on SOI Toposheet

Bifurcation Ratio (R b)

The bifurcation ratio, which is related to the branching pattern of the drainage network, is defined as a ratio of the number of streams of a given order (Nu) to the number of streams of the next higher order (Nu+1) and is expressed in terms of the following equation: R b= u/Nu+1

In the present study, the higher values of Rb indicate strong structural control on the drainage pattern, while the lower values are indicative of watersheds that are not affected by structural disturbances (Table 4).

Table 5: Bifurcation Ratio of Kumari Watershed

Stream Order	1st	2nd	3rd	4th	5th	6th	7th
Bifurcation Ratio	-	4.03	4.44	4.50	4.44	3.00	3.00

Source: *Prepared by the author based on SOI Toposheet*

Length Ratio

The proportion of increase of mean lengths of stream segments of two successive basin orders is defined as length ratio and is calculated according to the following equation: R L= Lu/ Lu-1

Horton (1945) states that the length ratio is the ratio of the mean of segments of order to the mean length of segments of the next lower order, which tends to be constant throughout the successive orders of a basin. In the present study, the stream length ratio varies from 0.25 to 1.15, and it expresses a change in length ratio from one order to another order. It indicates the youth stage to the early-stage mature stage of the basin. The value of the length ratio shows the variation in slope and topographical development of the study area.

Table 6: Length Ratio of Kumari Watershed

Stream Order	1st	2nd	3rd	4th	5th	6th	7th
Length Ratio	-	0.60	0.39	0.48	0.36	1.15	0.25

Source: *Prepared by the author based on SOI Toposheet*

Areal Analysis of Kumari River Basin

Basin area is a very important morphometric attribute as it relates to the spatial distribution of several significant attributes such as drainage density, stream frequency, drainage texture, slopes, absolute and relative relief, etc. The areal analysis of Kumari River Basin includes the study of stream frequency, drainage density, drainage texture, slopes, absolute and relative reliefs, etc.

Drainage Density

Drainage density is the total length of stream per unit area of drainage basin. The low value of drainage density indicates a highly permeable region (Horton, 1945). Horton expressed in terms of drainage density if of the following equation: Dd = Lu/A. The study area has been divided into a network of squares, and the length of the drainage line of each square has been measured by ArcGIS software. These values have been divided into 5 categories, ranging from less than 1 to more than 4 km^2. The study area reflects low drainage density and an easily erodible surface.

Primarily, the entire Kumari basin has been divided into a network of squares with a unit area of 1901.76 km2, and then the length of drainage lines within each square. These values have been grouped into four categories, ranging from 0.002 to 5.329 per square kilometre. These categories have also been grouped into three density zones, viz., coarse, medium, and fine, consisting of areas of 7.36%, 56.29%, 33.0%, and 3.04% respectively (Table No:7). It is quite clear from the adjoining drainage density map (Fig. 4) of the basin.

Table 7: Aerial Distribution of Drainage Density of Kumari Basin

SL No	Class	Category	Area In Sq. Km	Area In %
1	Below 1	Very Low	140.03	7.36
2	1 to 2	Low	1070.64	56.29
3	2 to 3	Moderate	633.35	33.30
4	Above 3	Very High	57.85	3.04

Stream Frequency

Stream Frequency or Drainage Frequency is the measure of the number of streams per unit area. For the computation of stream frequency (SF), the basin is conveniently divided into grid squares (more commonly one square mile/kilometre) depending on the map scale and area coverage of the basin, and the number of streams in each grid is counted, tabulated, and quantified. The high stream frequency indicates greater surface run-off and steep ground surface (Horton 1932, 1945). Horton expressed in terms of drainage density as the following equation: SF= Nu/A

In the present study, the drainage frequency varies from less than 3 to more than 12 streams per square km. These are tabulated at the class intervals of two streams per km^2 and their percentage values are given accordingly in Table 7.

Table 6 reveals that for the Kumari basin, approximately 65.95 % of the basin has a coarse drainage frequency, 6.19 % has a medium drainage frequency, and 0.77 and 0.01 % have fine and very fine drainage frequencies, respectively. The occurrence of medium drainage frequency near the confluence of two major streams is rather natural because the adjoining areas are affected by both of them, which speedily reduces its relief. Further, the increased mass of water rushing

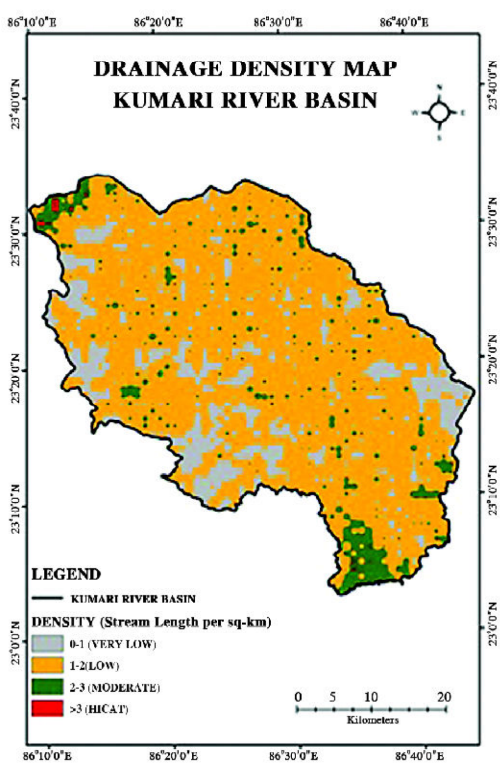

Fig. 3

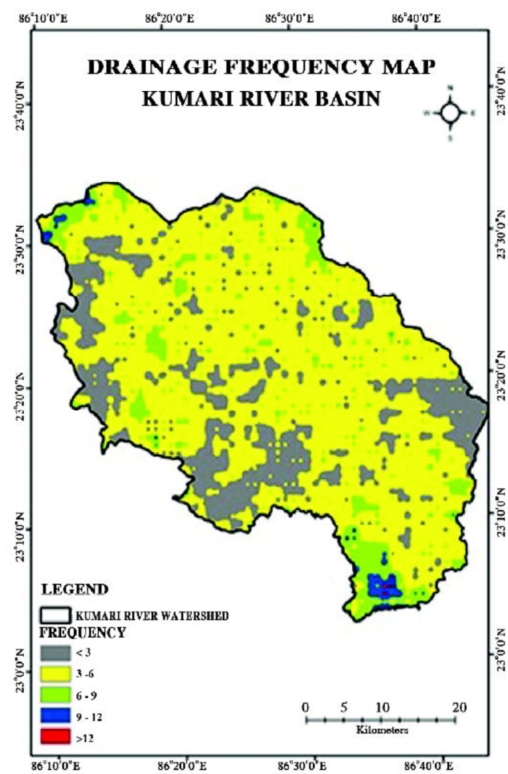

Fig. 4

***Source:** Prepared by the author based on SOI Toposheet*

through the river channel, below the confluence, tends to disperse the water to other directions, which leads to the formation of gullies and furrows on the banks. Thus, areas of medium drainage frequency are generally confined to the divides and ridge tops.

Table 8: Aerial Distribution of Drainage Frequency of Kumari Basin

SL No.	Class	Category	Area in Sq. Km.	Area in %
1	Below 3	Very Coarse	514.94	27.08
2	3 to 6	Coarse	1254.33	65.95
3	6 to 9	Medium	117.72	6.19
4	9 to 12	Fine	14.64	0.77
5	Above 12	Very Fine	0.24	0.01

***Source:** Prepared by the author based on SOI Toposheet*

Texture Ratio

Texture ratio is an important factor in the drainage morphometric analysis, which depends on the underlying lithology and relief aspect of the terrain. In the present study, the texture ratio of the watershed rises from 0.78 to 1.05. which fell within the coarse drainage texture.

From Factor (Ft)

The form factor may be defined as the ratio of the area of the watershed and the square of the watershed length (Horton 1932). The value of the form factor would always be greater than 0.78 for a perfectly circular basin. The value of the form factor of all sub-watersheds is less than 0.78 (a very small value), indicating that they are more elongated. The form factor is used to predict the flow intensity of a watershed of a defined area, and this has a direct linkage to peak discharge (Horton 1945, Gregory and Walling 1973). The form factor in Kumari Basin watersheds ranges from 0.06 to 0.86. Relatively large values of Ff (0.82) for the Nangasai sub-watershed indicate a higher flow peak for a shorter duration.

Circularity ratio (Rc)

The circulatory ratio is mainly concerned with the length and frequency of streams, geological structures, land use/ land cover, climate, relief, and slope of the basin. It is the ratio of the area of the basins to the area of the circle having the same perimeter as the basin. In the study area, the Rc values range from 0.34 to 0.76.

Elongation Ratio (Re)

Schumm (1956) defines elongation ratio as 'the ratio between the diameter of a circle with the same area as the basin and the maximum length of the basin'. The ratio approaches '1' (one) if the shape of the basin approaches a circle. Strahler states that this ratio varies between 0.6 and 1.0 over a wide variety of climate and geologic types. Values near 1.0 are found in typical regions of low relief, while values from 0.6 to 0.8 are generally associated with strong relief and steep ground slopes (Strahler, 1964). The result indicates that the elongation ratio varies between 0.179 and 0.489 in different sub-watersheds in the study area.

Relief Analysis of Kumari River Basin

Relief aspects refer to three-dimensional features of the basin, which include area, volume, and altitude of the landforms. In this study, the relief aspect involves the analysis of the slope aspect, average slope, absolute relief, relative relief, drainage texture, etc. Relief aspects are the most important factor in understanding the denudation processes of the river basin, and they indicate the flow direction of the water. Relief aspects are the result of various landforms of the basin.

Absolute Relief

Absolute relief is the measurement of the actual height of a particular area above sea level. The categorized of Kumari River Basin is five physiographic zones e.g. (< 126 m), (126– 252 m), (252 – 378 m), (378 – 504 m), (> 504 m), and the highest area covering between 126 – 252 meters. 7.2. Relative Relief is the difference between the high altitude and low altitude in a per unit area. This is used for the analysis of the geomorphological characteristics of landforms and the direction of the landform faces. The relative relief of the Kumari River basin is categorized into six types e.g. Very Low (< 15 meters), Moderately Low (15 – 30 meters), Low (30 - 60 meters), Moderate (60 – 120 meters), High (120 - 240 meter) and Very High (> 240 meter). In the study area, the region is a moderately low dissected area.

Relative Relief

Relative relief is the difference between the high altitude and low altitude in a per unit area. This is used for the analysis of the geomorphological characteristics of landforms and the direction

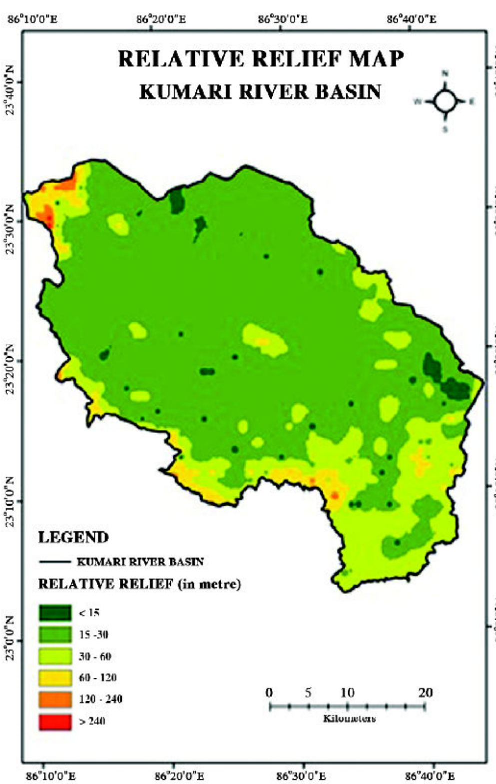

Fig. 5

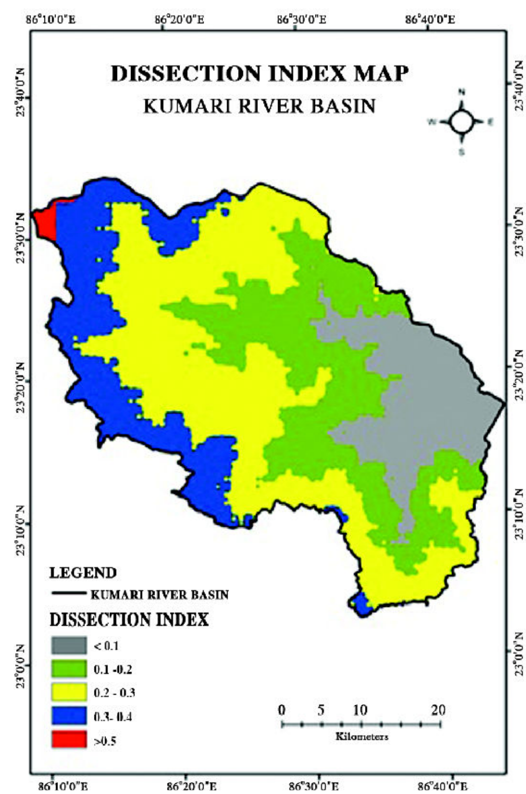

Fig. 6

Source: Prepared by the author based on the Landsat Image of the landform faces. The relative relief of the Kumari River basin is categorized into six types (Figure No: 05) e.g. Very Low (< 15 metre), Moderately Low (15 – 30 metre), Low (30 - 60 metre), Moderate (60 – 120 metre), High (120 - 240 meter) and Very High (> 240 meter). In the study area, the region is a moderately low dissected area.

Dissection Index

Dissection Index is a parameter referring to the degree of dissection or vertical erosion, and the stage of landforms development in any given watershed (Singh, S. and Dubey, A., 1994). The dissection index is the measurement of the vertical erosion landforms. Dissection index is the ratio of relative relief and absolute relief of the basin, which indicates 0 is the absence of Dissection and 1 is an extreme dissection of the landforms. In the study area, the dissection index lies between 0.2 – 0.3 (Figure No: 06) which indicates the Kumari River basin area is a moderately dissected landform and in the mature stage of geomorphic development.

Hypsometric Analysis

The hypsometric curve is the measurement and analysis of the relationship between altitude and basin area to understand the degree of dissection and stage of the cycle of erosion. Strahler (1952)

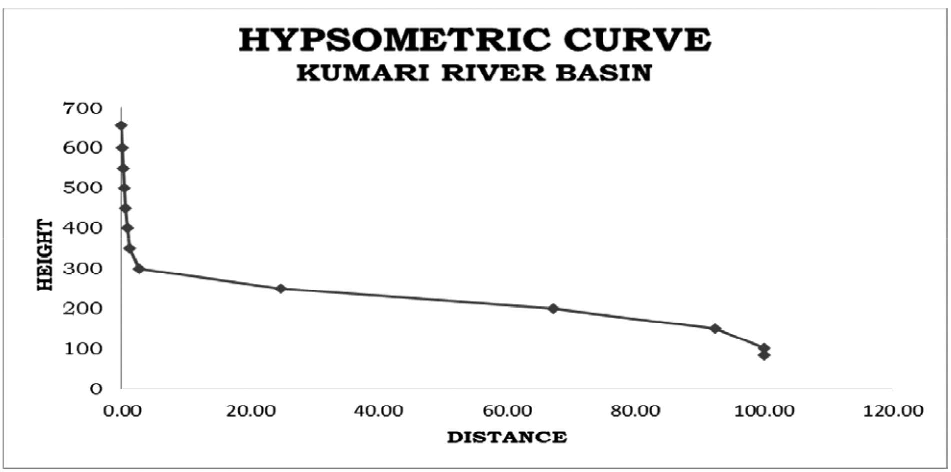

Fig. 7

Source: Prepared by the author based on primary data

Compared and evaluated different shapes of hypsometric curves about different drainage: basins and classified the basins according to their stages of geomorphological evolution as youth stage (convex upward curves, where HI ≥ 0.60), mature stage (S-shaped hypsometric curve which is concave upward at high elevations and convex downwards at low elevations, where 0.30 ≤ HI ≤ 0.60), and old stage (concave upward curve, where HI ≤ 0.30).

The hypsometric integral value of Kumari Basin falls under 0.50 (Figure No: 07), which indicates the mature stage of the watershed. The hypsometric curve diagram of the Kumari Basin also denotes that the whole landscape of the watershed has gone under prolonged denudational processes, and the entire watershed area has become now a land of planation surface of the Ranchi plateau region.

Conclusion

Morphometric analysis plays a crucial role in understanding the geomorphological structure and the underlying controlling factors that shape the landforms of a specific region. In the case of the Kumari River Basin, the analysis of various morphometric parameters has revealed significant insights into its geomorphic characteristics and developmental stage.

The calculated bifurcation ratio for the basin ranges between 3 and 4, suggesting a well-developed drainage network with moderate structural control, which points to some degree of geological disturbance within the basin. The drainage frequency, derived from the ratio of the total number of stream segments to the basin area, indicates a relatively low infiltration capacity and a surface that is prone to erosion. This is further supported by the drainage density values, which suggest a moderately dissected terrain.

One of the key findings is the hypsometric integral value of 0.50. This, along with the concave shape of the hypsometric curve, confirms that the Kumari River Basin is in the mature stage of geomorphic development. Such maturity reflects a balance between erosional and depositional processes, with reduced vertical incision and the dominance of lateral erosion.

The geomorphological mapping identified 16 distinct landform features across the basin. Among these, peneplain surfaces dominate the landscape, indicating a long history of erosional flattening. The combined analysis of linear, areal, and relief aspects reveals clear evidence of structural control influencing the evolution of the drainage network.

Overall, the morphometric and geomorphological assessment of the Kumari River Basin provides a comprehensive understanding of its drainage maturity, erosion potential, and geological influence—essential for future watershed management and sustainable land-use planning in the region.

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