World Journal of Advanced Engineering Technology and Sciences
eISSN: 2582-8266
Cross Ref DOI: 10.30574/wjaets
Journal homepage: https://wjaets.com/

(Research Article)

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Geospatial morphometric assessment of the Kumbhi river basin for sustainable water resource management

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World Journal of Advanced Engineering Technology and Sciences, 2025, 14(03), 528-537

Publication history: Received on 17 February 2025; revised on 26 March 2025; accepted on 29 March 2025

Article DOI: https://doi.org/10.30574/wjaets.2025.14.3.0173

Abstract

Morphometric analysis of drainage basins provides crucial insights into the hydrological characteristics of subsurface lithology, as well as the interplay of topography, geology, and climate in governing the spatial organization and morphology of fluvial networks. This study evaluates the hydrological attributes of the Kumbhi River basin, situated between latitudes 16°28'20.77"N to 16°44'0.35"N and longitudes 73°07'13.74"E to 74°49'31.91"E, as delineated on Survey of India (SOI) toposheet 47H/14. The Kumbhi River, originating near Lakhmapur Village (Taluka-Gaganbawada) in Kolhapur District, Maharashtra, serves as a principal tributary of the Panchganga River. Morphometric parameters were computed using advanced geospatial techniques in QGIS 3.16. The fifth-order Kumbhi River basin exhibits a dendritic drainage pattern, with a high stream frequency (5.21/km), infiltration number (14.32), and drainage density (2.75 km/km^2), indicative of significant surface runoff potential and a low constant of channel maintenance (0.36). The basin is characterized by a coarse drainage texture and an elongated morphology, contributing to enhanced runoff and limited infiltration capacity. Low values of the Rho coefficient suggest a reduced susceptibility to flood attenuation and increased discharge efficiency. Relief analysis indicates moderate to high elevation variations, implying relatively low to moderate infiltration rates and a predominantly overland flow-dominated hydrological regime. The region exhibits moderate to good groundwater potential. These findings contribute to the systematic classification of river basins, facilitating informed decision-making for sustainable water resource management and the strategic placement of water conservation structures, including check dams, percolation tanks, and artificial recharge systems.

Keywords: Morphometric Analysis; Drainage Basin Hydrology; Kumbhi River Basin; Geoprocessing Techniques; Runoff and Infiltration Potential; Water Resource Management.

1. Introduction

Three Greek words—Geo (earth), Morpho (form), and Logos (discourse)—combine to form the term geomorphology, which refers to the study of the earth's surface forms. Although landform mapping has been the focus of several studies in the 1960s and 1970s and dates to early geological research, landforms receive significantly less attention. The popularity of glacial and fluvial geomorphology has historically played a significant role in the growth of landform studies in the heavily inhabited, middle-altitude regions of the northern hemisphere that have been significantly impacted by glacial and fluvial processes. Nonetheless, there are significant differences in the status and customs of glacial geomorphology among nations.

A reliable indicator of rock permeability is the hydrological character of exposed rocks within a basin as determined by quantitative morphometric analysis in connection to geomorphological features, which can offer valuable information

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on yield potential for the watershed. Understanding basin processes and comparing their features is made easier by the study of basin morphometric parameters. Around the world, anthropogenic activities have had a significant effect on the biotic communities, physical characteristics of rivers and streams, and the biological processes of aquatic ecosystems. GIS techniques have been tested on several hydrological regimes and have quickly gained acceptance among Indian scientists and scholars (Bharath et. al., 2023; Patil, et. al., 2024).

Studying the origins and distribution of different landforms is related to fluvial geomorphology. Planning for both rural and urban settlement heavily relies on geomorphology. Human settlement cannot be planned appropriately without a scientific study of landforms. Morphometric parameters are primarily responsible for the geomorphology of each river basin. In order to increase food grain production, the agriculture sector has been under the most stress due to population growth, which has led to deforestation and increased water demand. There is a relationship between the various morphometric features of that basin and the water's infiltration capability. Utilizing cutting-edge methods to extract and preserve the limited water resources is therefore essential. Many scientists have investigated the geomorphological features of different basins utilizing conventional methods (Ghimire, 2020; Patil, et. al., 2021).

The efficient collection and analysis of spatial data is improved by the combination of remote sensing and GIS techniques. With the use of these technologies, intricate maps and models that depict different geomorphological aspects, like lineaments and drainage density, can be produced. Digital elevation models (DEMs) and satellite photos make it easier to identify groundwater potential zones and evaluate flood risks. By using these methods, scientists can gain understanding of the Kumbhi River Basin's geology and hydrology, which is crucial for efficient planning and management of water resources (Jayal, 2015; Gurav et. al., 2020; Patil and Bhagwat, 2023).

1.1. Study area

The study area is bounded by latitudes 16° 28' 20.77"N to 16° 44' 0.35" N and longitude 73°07' 13.74" E to 74 °49' 31.91" E on Survey of India (SOI) toposheet numbers 47H/14, 15 and 47L/2. Kumbhi River is one of the main tributaries of the Panchganga River. Kumbhi River originates near Lakhmapur Village (Taluka-Gaganbawada), Kolhapur District, Maharashtra

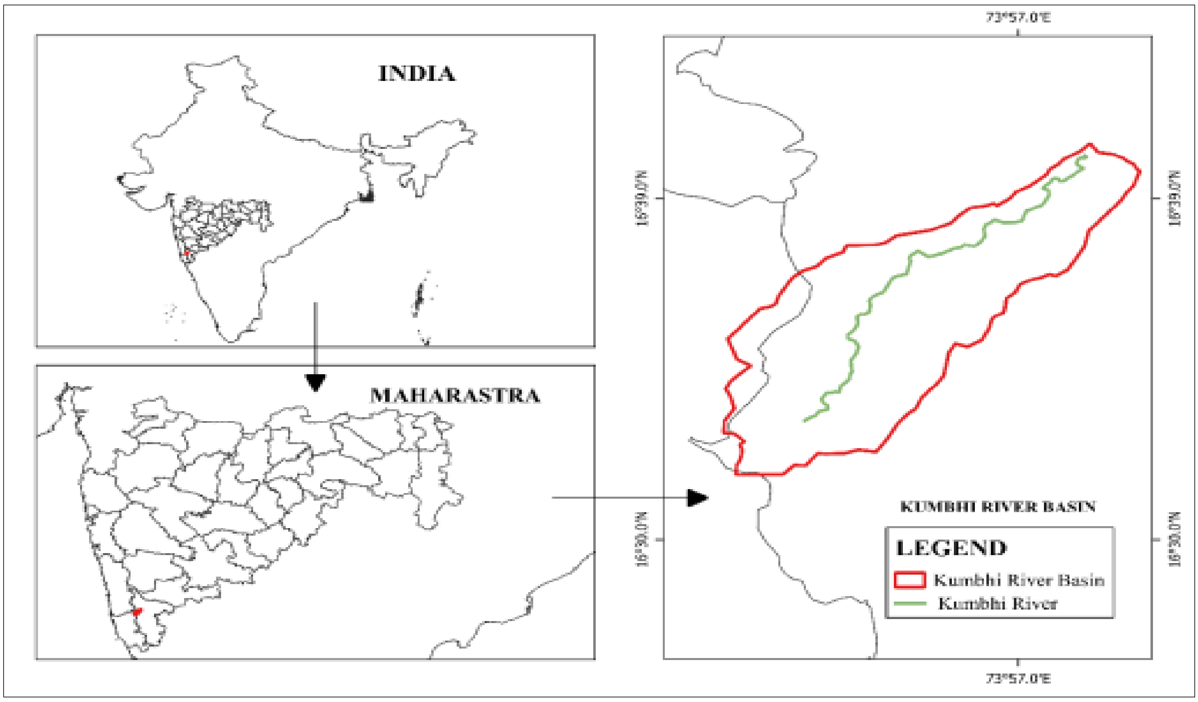

Figure 1 Location map of Kumbhi River Basin

2. Methodology

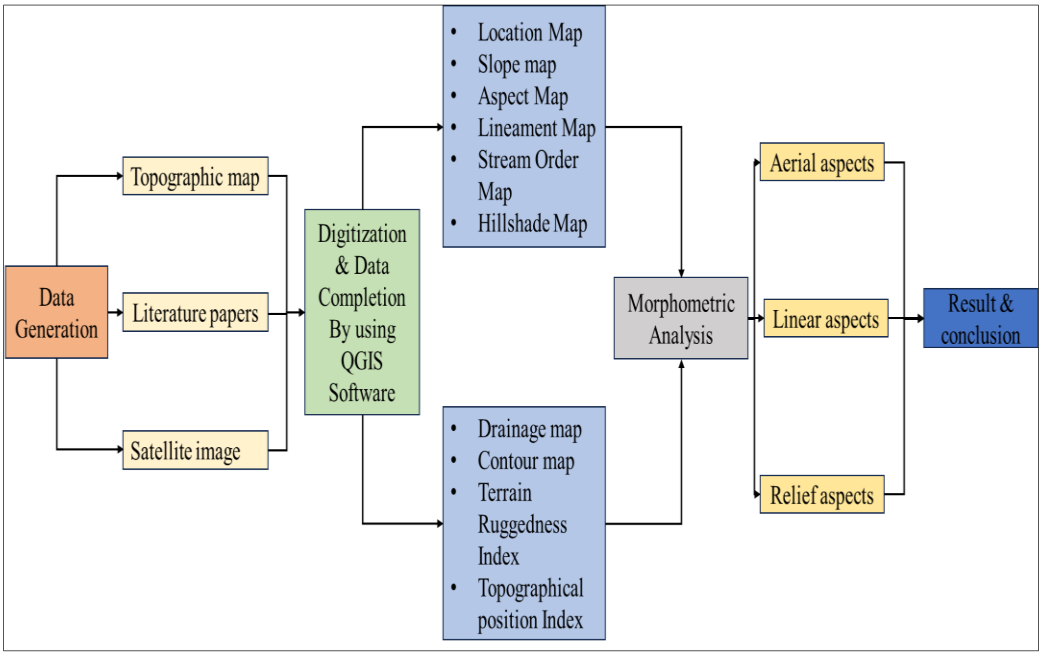

Figure 2 Flow chart of Methodology

The Kumbhi River basin's morphometry is examined using open-source Quantum Geographical Information Systems (QGIS) 3.16 software Survey of India Toposheets on 1:50,000 scales were used to prepare location map (Figure no.1). DEM-1-arc-30 meters resolution is used for preparation of contour map and DEM map. Toposheets were scanned, geo referenced and projected to UTM WGS (1984) datum and then digitized using the capabilities of QGIS software. Streams of the 1st and 5th order were marked by using Strahler method. A scale of 1:50,000 was used to digitize the river basin and its drainage network using Survey of India topographic sheets 47H/14, 15 and 47L/2. All the morphometric parameters were grouped into three categories arial Linear and relief components were established. A digital database for drainage networks was created to conduct additional morphometric study.

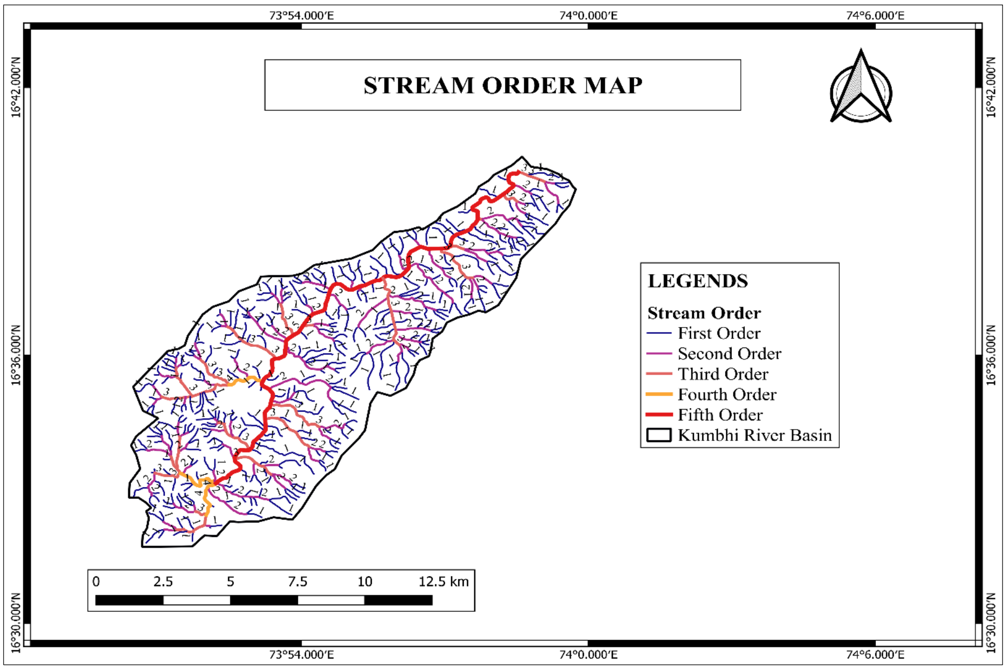

Figure 3 Stream Ordering Map

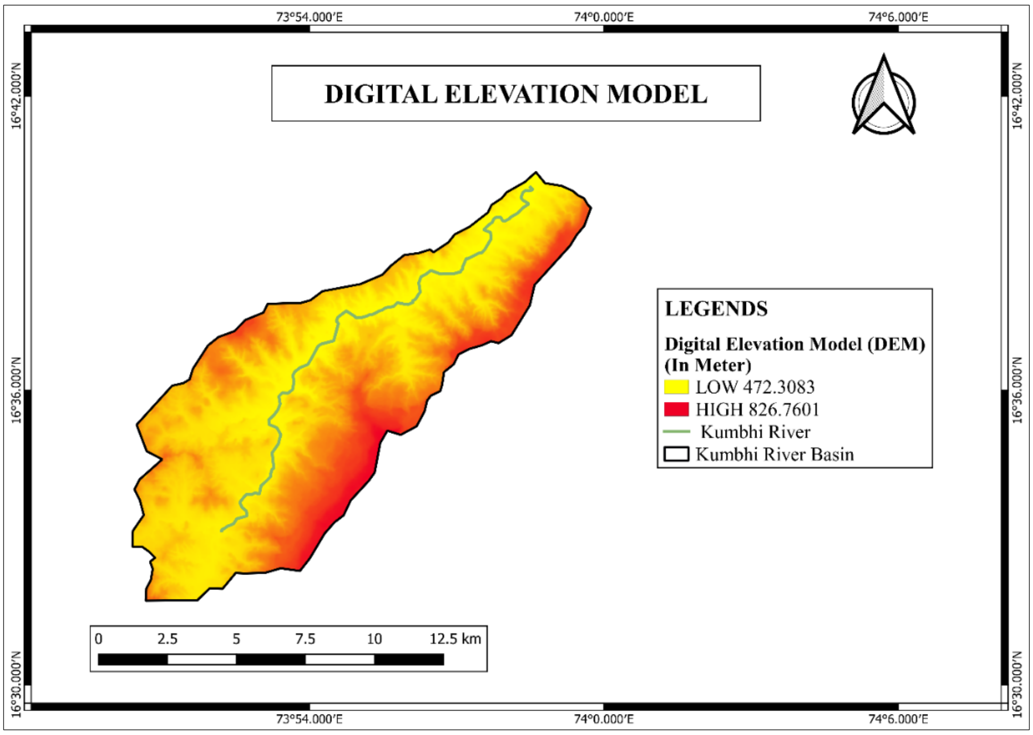

Figure 4 Digital Elevation Model

3. Morphometry

3.1. Basin Linear Aspects

3.1.1. Stream Order (U)

Numerical stream ordering is the initial stage in watershed analysis. Originally developed by Horton in 1945, the stream ordering techniques were updated by Stahl in 1952. When two first-order streams combine, they produce second-order streams; similarly, when two second-order streams combine, they become third-order streams. The first fingertip stream is referred to as a first-order stream. As more streams are added, the stream grows, and as order rises, the stream segment shrinks. This basin's highest stream order is fifth order (Fig.3).

3.1.2. Stream number (Nu)

The total number of stream segments in each order (Nu) is referred to as the stream number. Nu is the total number of streams of order u. There are 579 streams in the research region overall. In this basin, stream number (Nu) supports Horton's law, meaning that as stream order rises, stream number falls.

3.1.3. Stream length (Lu)

Horton proposed the law to determine a stream's length. The length of the stream may be one of the basin's most significant hydrological characteristics. The characteristics of surface runoff are shown. Sections of smaller streams feature finer textures and steeper slopes. As stream order increases, the overall length of stream segments decreases, with the first order stream frequently having the longest overall length (Horton, 1945). It counts the total number of streams of various sorts. From the mouth to the drainage division line, the length of these streams is determined. GIS software is used in this measurement.

3.1.4. Stream length ratio (L_{ur})

The ratio of the mean (Lu) of segments of order (u) to the mean (Lu-1) of segments of the next lower order (Lu-1) is known as the length ratio. Stream lengths tend to rise as stream order increases, with the mean length of stream segments in each successive order of a basin roughly following a direct geometric series. According to this investigation, the stream length ratio is 10.650 (Miller, 1953).

3.1.5. Mean stream length (L_{sm})

The distinctive size of a drainage network and the surfaces that contribute to it are revealed by the mean stream length (Lsm) of the network (Strahler, 1964). It is the ratio of the stream's length to the total number of streams. The mean stream lengths in the current study are the lowest (0.39) and largest (21.69), respectively. The basin's Lsm levels range from 0.39 to 21.69.

3.1.6. Bifurcation ratio (Rb)

Table 1 Drainage characteristics of Kumbhi River basin

Stream order (Su)	Stream number (Nu)	Stream length (Lu)	Bifurcation Ratio (Rb) (Nu/Nu+1)	Mean stream length (Lu/Nu)	Stream length ratio (Lu/Lu-1)
I	333	186.66	1.99	0.56	2.81
II	167	66.31	2.57	0.40	2.63
III	65	25.26	5.00	0.39	4.98
IV	13	5.08	13.00	0.39	0.23
V	1	21.69	NA	21.69	NA
Total	579	304.995	5.64		

Hortons created the bifurcation ratio (Rb) to represent the proportion of streams in a particular order to those in the next lower order (Patil & Patil, 20123). While (Strahler, 1964) proposed that a natural drainage system has a value of 3.0 to 5.0 in which geologic formations do not affect the drainage pattern, Horton states that the bifurcation ratio may range between 2 and 4. The bifurcation ratio in the current study is 5.64.

Table 2 Morphometric parameters of Kumbhi River basin

Parameters	Results
Stream Order	5
Stream Number (Nu)	579
Stream Length (Lu) (Km)	305.00
Stream Length Ratio (Lur)	10.650
Mean Stream Length Ratio (Lurm)	1.775
Basin Area (A) (Km^2)	111.05
Basin Perimeter (P) (Km)	53.75
Relative Perimeter (Pr) (Km)	2.07
Stream Frequency (Fs)	5.21
Drainage Density (Dd) (km/km^2)	2.75
Drainage Intesity (Di)	1.90
Maximum Elevation (Z)	826.761
Elevation at Outlet(z)	472.308
Length of Main channel (Ci)	160.4
Length of Basin (Lb)	22.55
Watershed Relief (H)	354.45
Relief Ratio (Rhl)	15.72
Absolute Relief (Ra) m	685.00

Dissection Index (Dis)	0.52
Ruggedness Index (Rn)	0.97
Watershed slope	2.21
Elongation Ratio	0.53
Form Factor	0.22
Circularity Ratio	0.48
Constant of Channel Maintainance	0.36
Length of Overland flow	0.18
Infiltration Number	14.32
Drainage Texture	10.77
Compactness Coe.	1.45
Slope	0.002
Time of Concentration	34.32

3.2. Basin Areal Aspect

3.2.1. Basin area

The basin area of the Kumbhi River is a crucial morphometric parameter, same like other metrics. The basin's total area is 111.05 square kilometres. Rainwater is likely to reach the main canal more quickly in a small basin than in a bigger one, where it must travel a greater distance (Patil et al., 2024). Drainage development in a given basin is expected to directly result in basin area.

3.2.2. Basin perimeter

The watersheds outside the borders that delineate a basin's perimeter are its perimeter. Watershed size and shape are measured along the watershed-to-watershed split. basin perimeter, which is 53.75 kilometres, using QGIS 3.16 software.

3.2.3. Elongation Ratio (Re)

The diameter of a circle with the same area at the basin divided by the longest length of the basin is known as the elongation ratio (Re) (Schumm, 1956). Geology and climate have an impact on the elongation ratio (Re), which typically falls between 0.6 and 1.0. Low relief is associated with values near 1.0, whereas large relief and a steep ground gradient are associated with values between 0.6 and 0.8 (Strahler, 1964). With an Elongation Ratio of 0.53 (Table 2), the Kumbhi River basin appears to have extended.

3.2.4. Form factor ratio (Rf)

The contour of the drainage basin can be determined using the form factor ratio (Rf), which is a dimensionless ratio of the basin's area to its square length (Horton, 1945). The shape factor of a fully round basin is higher than 0.785. The form factor of the basin diminishes with increasing basin length. While basins with low form factors have lower peak flows with longer periods, those with higher form factors have larger peak discharges with shorter periods. The Kumbhi River basin's form factor ratio, which is 0.22 (Table 2), indicates a longer duration between each peak and shows the basin's elongated structure (Pareta & Pareta, 2012).

3.2.5. Circulatory Ratio (Rc)

The size of the basin is divided by the area of a circle with the same circumference as the basin is known as the circulatory ratio (Miller, 1953). It is influenced by the length, frequency, and slope of streams of different orders, as well as basin drainage patterns and slope features (Strahler, 1957). Miller (1953) states that the basin's circulatory ratio ranges from 0.4 to 0.6, indicating that the geological material inside the basin is elongated and very permeable. The Kumbhi River basin's circulatory ratio of 0.48 suggests that it is an extended kind of basin.

3.2.6. Stream Frequency (F)

Horton (1964) defined stream frequency as the ratio of the basin's total area to the number of streams (Nu). It acts as a gauge for the drainage's proximity. While high drainage frequency indicates more surface runoff, low drainage frequency predicts more percolation, which increases the likelihood of groundwater (Patil and Bhagwat, 2023). It is a drainage basin metric for the development of runoff. The stream population in the Kumbhi River basin is increasing as drainage density rises, as evidenced by the positive correlation between the two variables and the stream frequency of 5.21/km (Table 2). Higher slopes and more rainfall in mountainous areas allow stream frequency (F) to rise (Pisal et.al., 2020).

3.2.7. Drainage density (D)

The drainage density (D), a gauge of the basin's wetness, is calculated by dividing the total length of streams in a catchment by the basin's area. In hydrological studies, it is a common geomorphological parameter that links the behavior of multiple watershed parameters (Rawat et.al., 2017). Numerous catchment factors are assessed, including soil, slope, climate, vegetation, lithology, land use, and the watershed's reaction to rainfall (Patil. et. al., 2021). Higher drainage densities are attained in areas with impermeable bedrock. Temperature, vegetation, rock formation permeability, weather resistance, and catchment geology all affect drainage density (D). Low drainage density (D) is observed in low relief, largely unaffected permeable materials with vegetation cover (Patil et al., 2024). The drainage density (D) is higher in regions with mountainous topography, low vegetation, and poor and impermeable underlying material. The Kumbhi River basin's drainage density (D) of 2.75 indicates that it is made up of impermeable terrain with modest relief.

3.2.8. Time of Concentration (Tc)

One important factor in watershed analysis is the time of concentration. Time of concentration is the maximum duration required for a particle to go from a watershed divide to the watershed outlet (Patil and Bhagwat, 2023). It is used to calculate the peak discharge of the watershed. The Kirpich equation is used to calculate the time of concentration. The watershed's average slope (S), longest water course (L), and a coefficient that indicates the kind of groundcover are necessary inputs for determining the period of concentration. "L" and "S" are found using QGIS 3.16 (Table 2), and the equation is used to determine the time of concentration.

$$Tc=0.0662*L^{0.77}*S^{(-0.305)}$$

The Kumbhi River basin's hydrograph is characterized by a high peak and a moderate to high base period, as indicated by the concentration time of 28.45 hours (Table 2).

3.2.9. Overland flow length (Lo)

It is the amount of time it takes for rainwater to localize into the channel after it hits the ground. Lo is separated into three groups based on low values (0.3). Flash flooding is more likely when low Lo values are associated with high relief, shorter flow routes, increased runoff, and decreased infiltration (Horton, 1945). The Kumbhi River basin's low values (Table 2) suggest that there is moderate infiltration and runoff, which increases the region's vulnerability to flooding.

3.2.10. Infiltration Number (If)

The infiltration number, which is a function of drainage density and stream frequency, represents the infiltration properties of the river basin (Patil, et. al., 2024). Runoff and infiltration number are positively correlated; lower infiltration number values (10) indicate a high possibility for runoff, which translates into very low penetration. With an infiltration number of 14.32 (Table 2), the Kumbhi River basin has moderate to high discharge due to infiltration.

3.3. Basin Relief Aspects

3.3.1. Relative relief

The relative elevation difference between a morphological feature and its surroundings, such as the height difference between a peak and its surroundings, the depression and its surroundings, etc., is known as terrain relative relief (or elevation) (Patil and Bhagwat, 2023). The height differential between the highest and lowest points (the greatest variation in elevation between two sites) in a basin or area is known as the amplitude of relief or local relief. Watershed values are determined in this study using SRTM data.

3.3.2. Dissection Index

The dissection index, which always ranges from zero (no dissection) to one (vertical cliff at seashore), is the ratio of a basin's relative relief to its absolute relief. Landscape dissection is one of the elements that influences drainage density (Patil and Bhagwat, 2023). Differential cutting of the formerly smooth land surface causes the dissection index value to rise during the landform development cycle. This suggests that greater dissection takes place as a result of imperfections, leaving a simple surface.

3.3.3. Relief Ratio (Rhl)

The term "total relief of the river basin" refers to the distance between a watershed's highest and lowest points. According to Schumm (1956), the relief ratio is the ratio of a basin's total relief to its longest dimension, which runs parallel to its main drainage line. The value for this study area is 15.72.

3.3.4. Maximum elevation

The greatest height of the basin is the highest point on the watershed. QGIS software says it's 826.761 meters.

3.3.5. Elevation at outlet

The lowest elevation on the watershed or the watershed's outlet is known as the basin mouth height. It has been calculated to be 472.308 meters using QGIS software.

3.3.6. Interrelationship between various morphometric parameters

The sub-basins are evaluated for flood estimation and recharge potential (Fig. 5a & 5b) using the relationship between drainage density v/s bifurcation ratio and stream frequency v/s bifurcation ratio (Patil and Bhagwat, 2023).

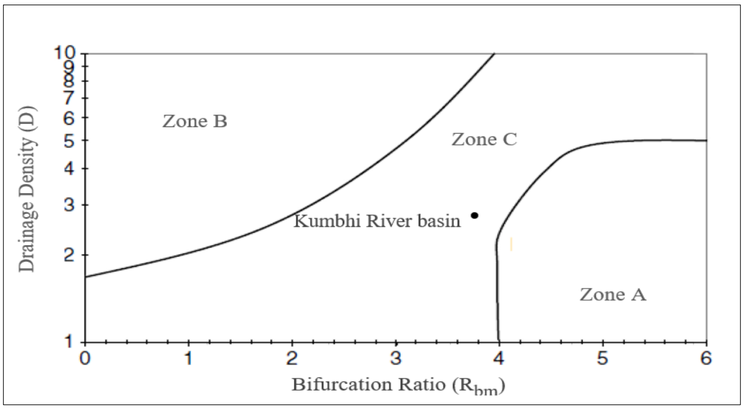

Figure 5a Plot between Bifurcation ratio v/s Drainage Density Plot of bifurcation ratio v/s drainage density for the subbasins located in different agro climatic zones

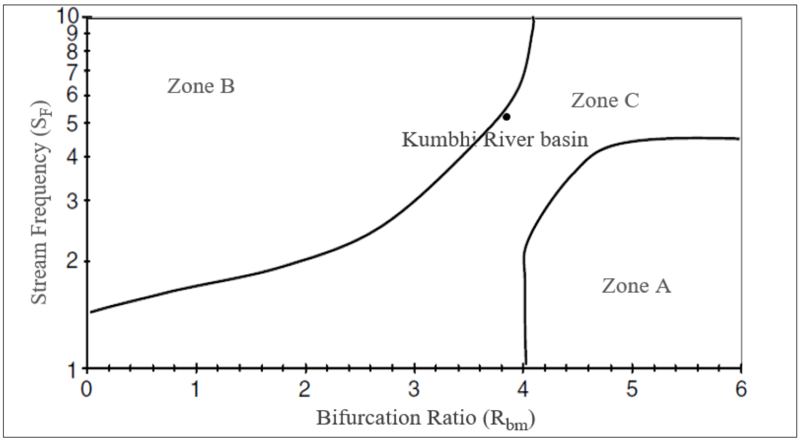

Figure 5b Plot of Bifurcation ratio v/s Stream frequency for the sub-basins located in different agro climatic zones.

- Zone A: Low flood probability and high recharge property,
- Zone B: High flood probability and low recharge property,
- Zone C: Moderate to high flood property and moderate recharge property.

Results of the above graph

Based on bifurcation ratio, Drainage density and Stream frequency of Kumbhi River Basin lies under “Zone C”. This implies that Kumbhi River basin have Moderate to high flood property and moderate recharge property.

4. Conclusion

Morphometric analyses of the basin region are very helpful for surface water harvesting and watershed management plans. As a result of the above study, it is concluded that Kumbhi River lies in “ZONE C” (Fig.5a & 5b) which indicates Moderate to high flood property and moderate recharge property. The average (Rb) bifurcation ratio value of 5.64 (Table 1) suggests that the basin is not much affected due to structural disturbances. Length of Overland Flow value of Kumbhi River Basin is 0.18 indicating low runoff, flow-path, ground slope, and infiltration. It has been determined that percolation occurs on hard-rock terrain at joints, lineaments, or faults, and locations where lineaments intersect are potential sites for artificial recharge. The extent of drainage and morphometric characteristics of a basin are potential indicators of its response to hydrology. Percolation is also affected by fluctuating ground water levels, soil cover thickness, land use, and rainfall patterns in a basin. To identify a potential area for recharge, all these parameters need to be considered, and the multicriteria approach allows us to identify suitable areas. The results of the study will be useful in classifying river basins for the development and management of water resources in the future as well as in identifying the most advantageous locations for the construction of water-conservation infrastructure such as artificial groundwater recharge, check dams, and percolation tanks.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Bharath, A., Maddamsettya, R., & Pawar, R. (2023). Evaluation of the geomorphological scenario of Shimsha River Basin,Karnataka, India. Water Science & Technology, 87 No 8, 1907

[2] Ghimire, M. (2020) .Basin characteristics, river morphology, and process in the Chure-Terai landscape: A case study of the Bakraha river, East Nepal. The Geographical Journal of Nepal, Vol. 13: 107-142

[3] Gurav, C., Babar, M. D., & Jagdale, A. (2020). Morphotectonics Study of Dhamani River Basin in Kolhapur District, Maharashtra, India. Bulletin of Pure and Applied Sciences, Vol.39, 131-149.

[4] Horton, R. E. (1945). Erosional development of streams and their drainage basins, a hydro-physical approach to quantitative morphology. Geological Society of America Bulletin, 56(3), 275–370.

[5] Jayal, T. (2015). Study of geomorphology and drainage basin characteristic of kaphni glacier, Uttarakhand, India. International Journal of Interdisciplinary and Multidisciplinary Studies, Vol 2, No.7, 35- 48.

[6] Miller, V. C. (1953). A quantitative study of drainage basin characteristics in the mountain area. Virginia and Tennessee (Technical report, Office of Naval Research, Department of Geology, Columbia University, New York).

[7] Pareta, K. R., & Pareta, U. (2012). Quantitative Geomorphological Analysis of a Watershed of Ravi River Basin, H.P. India. International Journal of Remote Sensing and GIS, Vol 1, Issue 1, 47-62.

[8] Patil SK, & Bhagwat TN (2019). A review of synthetic hydrograph method for design storm. International Research Journal of Engineering and Technology 6. 2413-2418.

[9] Patil, S. K., Sajane, A. S., & Ingale, A. S. (2021). Water resources development and dauses of flood blossoming in Upper Krishna river basin. International Journal of Application or Innovation in Engineering & Management (IJAIEM), 10(7), 70-76.

[10] Patil SK, & Bhagwat TN (2022) Hydromorphometry of the Warana River Basin Maharashtra, India: An Insight for Irrigation Water Management in Agricultural Dominated Area. Bulletin of Pure & Applied Sciences-Geology 41(2). 182-195.

[11] Patil SK, & Bhagwat TN (2023). Morphometric analysis and hydrological inferences for water resource management in Warana River basin of Maharashtra, India, using remote sensing and GIS. Songklanakarin Journal of Science and Technology 45(1). 113-120.

[12] Patil, S. K., Bhagwat, T. N., Sajane, A. S., Mulla, A. L., & Patil, G. S. (2024). Hydrological and Morphometric Assessment of the Warana River Basin, Maharashtra, India: Informing Irrigation Water Practices in Agricultural Dominant Landscapes. Research Advances and Challenges in Agricultural Sciences, 6, 105-123.

[13] Patil SK, Mulla AL, Sajane AS (2024) Topographic and subterranean structural mapping utilizing aerial magnetic and remote sensing data Songklanakarin Journal of Science & Technology 46(4). 390-397.

[14] Patil, S. K., Lambe, J. S., & Patil, D. S. (2024). Prioritizing Flood-Prone Areas In Warna Basin, India With Analytic Hierarchy Process. Suranaree Journal of Science & Technology, 31(6).

[15] Patil, S. K. ., Sajane, A. S. ., Lambe, J. S. ., Sakhare, V. D. ., Dixit, A. S. ., Pise, P. A. ., Rodrigues, J. S. ., & Hajare, A. V. . (2025). Integration of Morphometric Analysis and Synthetic Unit Hydrograph Methods for Hydrological Assessment in the Warana River Basin, Maharashtra, India. Engineering Research: Perspectives on Recent Advances Vol. 4, 48–72. https://doi.org/10.9734/bpi/erpra/v4/4164

[16] Patil, Y. A., & Patil, A. J. (2023). Geomorphometric Analysis to Deduce Groundwater Potential of Kumbhi River Basin, Kolhapur District, M.S. India. International Journal of Research in Academic World (IJRAW), 2(5):14-18.

[17] Pisal, P. A., Hivarekar, S. B., Patil, R. A., & Bhosale, H. D. (2020). Geomorphology Of The Bhogavati River Basin, Kolhapur District, Maharashtra, India. International Journal of Advanced Research, 8(06), 668-682.

[18] Rawat, U., Awasthi, A., Gupta, D. S., Paul, R. S., & Tripathi, S.(2017). Morphometric Analysis using Remote Sensing and GIS Techniques in the Bagain River Basin, Bundelkhand Region, India. Indian Journal of Science and Technology, Vol 10 (10).

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

[20] Strahler, A. (1957). Quantitative analysis of watershed geomorphology. Transactions of American Geo physical Union, 38, 913-920.

[21] Strahler, A. N. (1964). Quantitative geomorphology of drainage basins and channel networks. In V. R. Chow (Ed.), Handbook of Applied Hydrology (pp. 40–74).