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Quantitative Morphometric Analysis Using Remote Sensing and GIS Techniques for Kajali River Watershed

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Abstract: The current study was morphometric analysis of Kajali River watershed which is located in Ratnagiri District, Maharashtra. It had tropical wet climatic conditions with high precipitation. The objective of this research study is to apply morphometric approaches and use GIS and RS tools to analyse their properties. The Linear, Areal and Relief morphometric aspects are analysed. After investigation, Kajali basin occupied porous laterite rock. Stream networks of basin were classified up to 5th order. Drainage density of basin is 0.856 km/km2 which displayed permeable nature of soil with high relief. Drainage texture is 1.708 km/km, reflects coarse drainage texture whereas Stream frequency is 0.609km which reveals low runoff values and permeable surface of basin. Form factor and Elongation ratio values are 0.135km and 0.415 respectively which reflects elongated shape of watershed, High relief, low susceptibility towards erosion and have minimum sediment load. Due to low value of circulatory ratio (0.109) the watershed is less susceptible to flooding. Minimum elevation of watershed is 0 m i.e. Mean Sea Level (MSL) and maximum elevation of watershed is 914 m from which basin relief was calculated as 914 m which shows high undulations in basin. Value of ruggedness number is 0.783 which indicate that watershed has highly rugged surface.

***IndexTerms* - Morphometric, Linear, Areal, Relief, Precipitation.**
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Introduction

The process of developing and carrying out strategies, plans, and initiatives to maintain and improve watershed functioning is known as "watershed management", which have an impact on the populations of humans, animals, and plants inside a watershed limit. It is primarily concerned with controlling human activity's impact on natural resources rather than the resources themselves. The river's drainage basin acts as a natural barrier to regulate and lessen interactions between people and the environment. Watershed management requires collaboration since human activity encompasses the acts of the state, local governments, businesses, and landowners. Inadequate water quality, erosion, floods, and shortages of communal water may all be avoided with effective watershed management. The cost of managing a watershed now is significantly lower than the cost of clean-up later on (Jankar et al. 2013). Understanding the intricate interactions between a specific watershed's relief, linear, and areal features requires a thorough understanding of morphometric analysis. To aid with this study, a database is established by measuring several land surface and drainage factors. One of the most important steps in developing theories and plans for the development of water resources is calculating morphometric parameters. Researchers may learn more about the geometry, dimensions, and form of watersheds, as well as the features of their drainage patterns, by using morphometric analysis. Understanding hydrological processes, forecasting runoff patterns, identifying flood-prone locations, and developing effective water resource management plans are all made possible by this information (Sukristiyanti, Maria, and Lestiana 2018). Researchers can determine quantitative linkages and trends by computing morphometric parameters, such as relief, basin form, drainage density, stream lengths, and other factors. This makes it possible to better understand the behaviour and hydrological response of the watershed on a deeper level (Raja Shekar and Mathew 2024). Given their scarcity as natural resources and the expanding human population, land, water, and soil pose significant concerns for broad utilization. In order to ensure sustainable growth, it was imperative to prioritise the protection of natural resources and reduce the imbalances in supply and demand for them. In this context, the development of GIS and remote sensing technologies opened up new avenues for morphometric research. In recent decades, those methods had been applied to natural resource planning and management. in different ways (Suresh and Krishnan 2022). Numerous scientists were employed in the mapping of the groundwater potential zone, the monitoring of command areas, the modelling of rainfall-runoff, and numerous other GIS and remote sensing applications (Qadir et al. 2020).

2. Study Area

The study area, Kajali River basin, Ratnagiri district, Western district of Maharashtra, located in west India, with Easting 73016' and Northing 73017'. Kajali River originates from the foothills of Sahyadri hills in Kolhapur district and passes through the western direction of Ratnagiri district and meets the Arabian Sea. The length of Kajali River is 60 km which is western flowing river and it joins the Arabian Sea at Bhatye near Ratnagiri. The Kajali River basin has an aerial extent of 452.559 km^2. Kajali watershed basin consists of 3 tehsils from Ratnagiri district namely, Ratnagiri, Lanja, Sangmeshwar, and 1 tehsil from Kolhapur district namely Shauwadi. The topography of this region is highly uneven. In this area you will find extremely narrow riverine plains adjoining the coastline. It has a minimum elevation of mean sea level (MSL) in the west, and a maximum elevation of 914.05 m above the MSL in the east. The study area experiences rainfall through the southwest monsoon with an average annual rainfall of 3,188 mm. being a coastal region the climate is moist, humid and there is heavy rainfall. The fertile alluvial valleys yield coconuts, cashew nuts, rice and various fruits. The Kajali River basin made up of laterite and Basalt rock type and has Laterite and acidic coarse, shallow soil in basin. Watershed has Mumbai-Goa national highway (NH 66) and passing through it. There is also a part of Konkan Railway passing through it. Along the path of Konkan railway in the watershed Ratnagiri, Nivsar and Adavli these stations are present. Bav river watershed is at north of Kajali watershed whereas Muchkundi river watershed is at south direction. Hatkhamba, Nachne, Sakhrpa, Adavli and Ratnagiri are main cities in watershed.

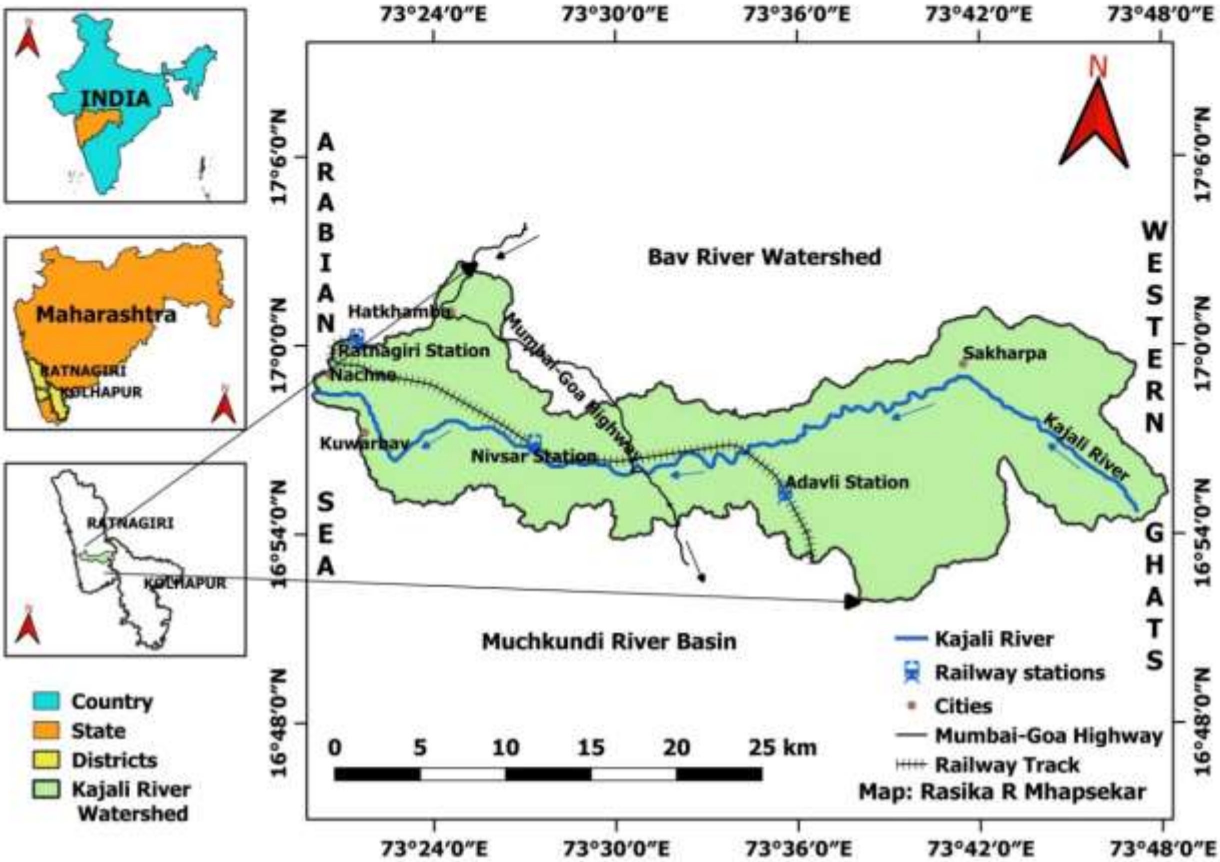

Figure 1: Study Area Map

3. RESEARCH METHODOLOGY

The methodology section outlines the plan and method that how the study is conducted. The details are as follows;

3.1 Data and Sources of Data

CartoDEM of 30-meter resolution was used which is downloaded from Bhuvan portal. Village Boundary Database was downloaded from SOI portal. Sentinel 2A Rater Data of 10-meter resolution was downloaded from EOS Land Viewer Portal. India Admin Boundary was downloaded from SOI portal. For this research work I have used QGIS software which is open-source software in which we can add, subtract and manipulate data easily. This Software allows users to analyse and edit spatial information to composing and exporting graphical maps.

3.2 Methodology

This work primarily relies on morphometric evaluation to analyse the hydrological influence from the Kajali basin for water resource management. Using CartoDEM data, the drainage network and border of the Kajali basin were derived. It has also been utilised to compute aspect and slope maps. The remote sensing data were acquired from the EOS Land Viewer website (https://eos.com/landviewer). Google Earth images are also used for the cross verification of outcomes of the Sentinel data. The development of stream networks depends on geology, rainfall of the area. The basin demarcation and the related hydrological analysis of streams have been done in QGIS 3.18.1 software. The study computed the morphometric parameters' linear, areal, and relief aspects. With the use of spatial analysis tools, these parameters were created from the streams recovered from CartoDEM data. Using previously developed mathematical formulae, a number of selected morphometric characteristics such as drainage density, bifurcation ratio, drainage frequency, circulatory ratio, elongation ratio has been computed. Stream ordering methods have been successfully applied for the characterisation of watershed and drainage network.

3.3 Watershed Delineation

To identify the study area, delineation of the Kajali River basin is important, and a primary step was performed. To delineate the watershed, CartoDEM of 30m resolution was used, which is downloaded from the Bhuvan portal. The coordinate system was adjusted to obtain 'EPSG:32643 - WGS 84 / UTM zone 43N - Projected' CRS and used as an input to run the fill sinks tool to fill sinks in Digital Elevation Model (DEM), if any present. The filled DEM obtained was used as input to run Strahler order tool to find streams in DEM. The tool allows the determination of an outlet point that was used in the Upslope Area tool. Using the coordinates of the outlet, the area upstream of the river can be obtained, which is the total watershed. This area was in raster to convert it into vector form Vectorise tool is used. Required area of watershed is exported and used for further processing.

3.4 Maximum Flow Length

To obtain the channel network, clipped filled DEM was used as input to run the 'Channel network and drainage basin tool'. An appropriate symbology was given to the output channel network. Channels were merged according to their orders. The maximum flow path was merged to find the maximum flow path and then saved editing in the layer.

3.5 Parameter Calculation

Morphometry and morphometric analysis are qualitative measurements and the mathematical analysis of landforms, generally performed on the watershed or area of interest to understand its geo-hydrological characteristics. It is split into three main parameters, namely linear, areal and relief parameters.

Table 1: Parameters Calculated and their Formulae

Sr.No.	Linear Parameters	Formula	References
1.	Stream Order (Nu)	Hierarchical rank	Strahler, 1964
2.	Stream Length (Lu)	Length of the Stream in km	Horton, 1945
3.	Mean Stream Length (Lsm)	Lsm = Lu/Nu Where, Lu = Total stream length of order ‘u’; Nu = Total no. of stream segments of order ‘u’	Horton, 1945
4.	Stream Length Ratio (RL)	RL= Lsm / Lsm-1 Where, Lsm=Mean stream length of a given order; Lsm-1= Mean stream length of next lower order	Horton, 1945
5.	Bifurcation Ratio (Rb)	Rb = Nu / Nu +1 Where, Rb = Bifurcation Ratio; Nu = No. of stream segments of a given order; Nu +1= No. of stream segments of next higher order	Schumn, 1956
6.	Mean bifurcation ratio (Rbm)	Rbm = Average of bifurcation ratios of all orders.	Strahler, 1957
	Areal Parameters	**Formula**	**References**
1.	Drainage Density (Dd)	Dd = Lu/A Where, Dd = Drainage Density (1/km); Lu = Total stream length of all orders; A = Basin Area (km2)	Horton, 1945
2.	Stream Frequency (Fs)	Fs = Nu/A Where, Fs = Stream Frequency; Nu = Total no. of streams of all orders and; A = Area of the basin (km2)	Horton, 1945
3.	Drainage Texture Ratio (T)	T = Nu /P Where, Nu = No. of streams in a given order; P = Perimeter of basin (km)	Horton, 1945
4.	Form Factor (Ff)	Ff = A/Lb2 Where, A = Basin Area; Lb = Basin length	Horton, 1945
5.	Circulatory Ratio (Rc)	Rc = 4πA/ P2 Where, A = Basin area (km2); P= Perimeter of the basin (km)	Miller, 1953
6.	Elongation Ratio (Re)	Re= √A /π / Lb Where, A= Basin area (km2); Lb= Basin length (km)	Schumn, 1956
	Relief Parameters	**Formula**	**References**
1.	Basin Relief (Bh)	Bh=H-h Vertical distance between the lowest and highest points of watershed	Schumn, 1956

2.	Relief Ratio (Rr)	Rr= H / Lb Where, H = Basin Relief (km); Lb = Basin length (km)	Schumn, 1956
3.	Ruggedness Number (Rn)	Rn = H x Dd Where, H = Basin Relief (km); Dd = Drainage Density	Patton & Baker, 1976

4. RESULTS AND DISCUSSION

4.1 Linear Parameter Analysis

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 analysed. Linear aspects include Stream order (U), Stream number (Nu), Stream length (Lu), Mean stream length (L_{sm}), Stream length ratio (Rl) and Bifurcation ratio (Rb). Stream ordering, the first step in morphometric analysis of drainage basin analysis, is a measure of the position of a stream in the hierarchy of tributaries. Such ordering of the streams is an essential input towards estimating several other drainage morphometric parameters considered for the present study. The channel segments have been ranked according their tributaries that is 1st order stream has no tributaries, 2nd order streams have tributaries only of 1st order streams and by joining two 2nd order, 3rd order stream is formed and so on. In this study area the highest order is five. Basin length is the longest length of the basin, from the catchment to the point of confluence and this measure is essential to estimate the shape, and also the relative relief of the watersheds. The length of watersheds of the study area estimated is 48.449 km. Stream number of a watershed refers to the number of stream segments within a watershed. Total count of streams is 276 in watershed. Out of total count there are 217 streams are of 1st order, 47 are of 2nd order, 9 are of 3rd order, while there are only 2 streams are of order 4 and only single stream of order fifth. The average length of streams of each order in a drainage basin tends closely to approximate a direct geometric ratio. The total length of stream segments generally decreases with increasing stream order. The total stream length of all stream segments is 387.7676 km. The total length of 1st order is 187.906 km, 2nd order is 89.7203 km, 3rd order is 51.206 km, 4th order is 22.3079 km and 5th order is 36.6274 km. The mean stream length varies from 0.8659 to 36.6274 respectively 1st orders to 5th order. The mean stream length of a particular order is greater than that of next lower order and less than that next higher order. The mean length of a channel is a dimensional property and reveals the characteristic size of drainage network components and its contributing basin surface. Total L_{sm} value of watershed is 56.2458. The stream length ratio can be defined as the ratio of the total stream length of a given order to the total stream length of next lower order and having important relationship with surface flow and discharge. Mean stream length ratio is 0.781. The bifurcation ratio of various order streams in Kajali watershed varies between 2.00 to 5.22. Rb values Illustrates that watershed falls under normal basin category. Mean bifurcation ratio of watershed is 4.08. It indicates that the area has not suffered geological structural disturbance.

4.2 Areal Parameter Analysis

Areal aspects express the overall plan form and dimensions of drainage basins. Areal aspects include Drainage Density (Dd), Stream Frequency (Fs), Drainage Texture (T), Form Factor (Ff), Elongation Ratio (Re) and Circularity Ratio (Rc) are discussed. Drainage density is defined as the total length of all streams in a basin divided by the area of the basin. It describes the spacing of channel. Dd varies between the ranges of 0 to 8. Low value of drainage density Dd indicated that the region is having permeable subsoil material under vegetative cover and it also indicates the watershed has low relief, whereas high Dd is favoured in regions of weak or impermeable subsurface materials, sparse vegetation and mountainous relief. Low drainage density leads to coarse drainage texture whereas high drainage density leads to fine drainage texture. The watershed had 0.85683 Drainage density values which indicate that it has Low drainage density usually result in highly resistant or permeable under soil materials, dense vegetation, and shallow relief areas. Drainage density ranges between 0 to 8. Drainage density classified into five different classes of drainage texture, i.e. less than 2, indicates very coarse, between 2 and 4 is coarse, between 4 and 6 is moderate, between 6 and 8 is fine and greater than 8 is very fine drainage texture. The study area had value 1.70487 which indicates that watershed had very coarse drainage texture. Flooding is commonly occurring in a basin with high drainage and stream frequency. Fs value of Study area is 0.60986 which indicates low runoff also has permeable sub-surface and low relief. Form factor (F), an index for determining the shape of the basin has been made use of for the purpose. The study area had form factor value 0.1356 which indicate that watershed had elongated shape and have flatter peak flow for longer duration. Kajali watershed has a 0.4156 Elongation Ratio which reflects its elongated shape moderate relief and moderate slopes, this indicates that the sub basins are moderately susceptible to erosion and have minimum sediment load. Circularity ratio is the ratio of the basin area to the area of a circle having the same circumference perimeter as the basin. It is dimensionless property and expresses the degree of circularity of the basin. Sub watershed had circulatory Ratio value 0.109 which indicate that Basin is elongated and less susceptible to flooding.

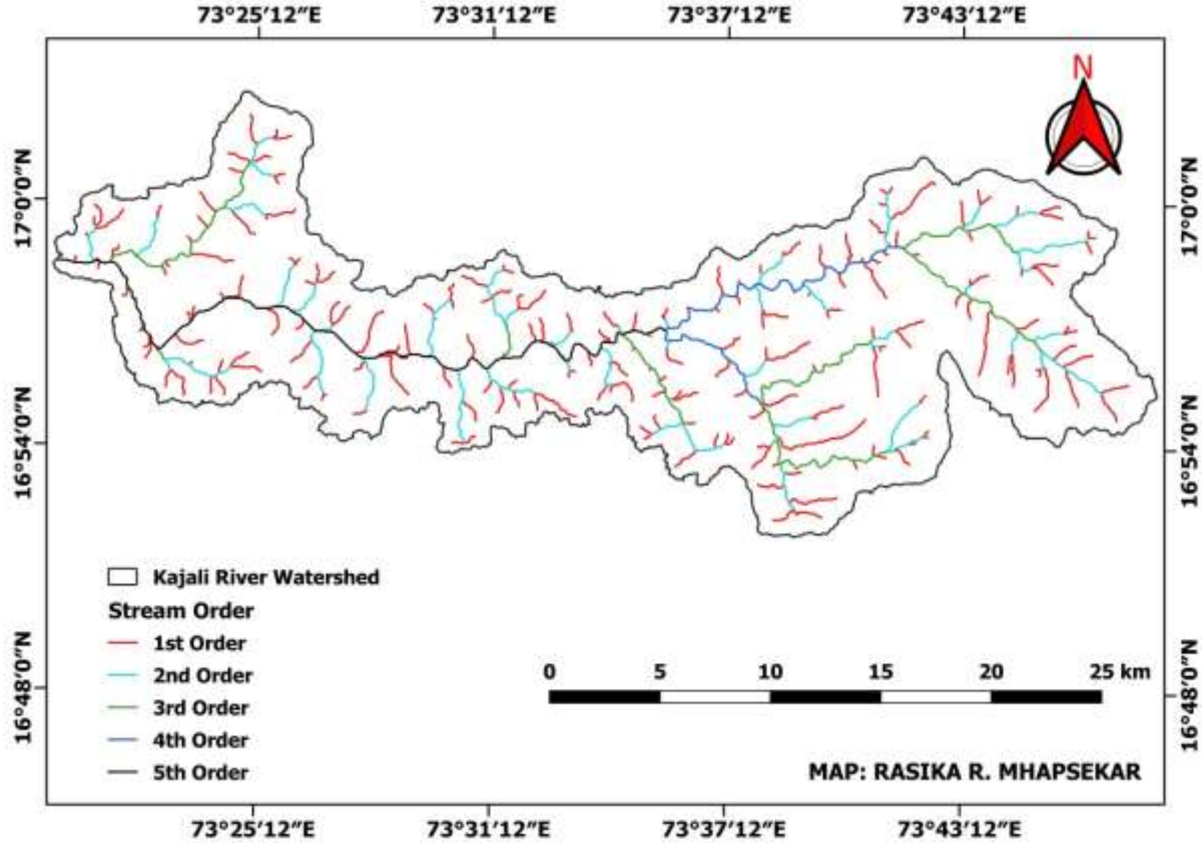

Figure 1: Stream Network of Kajali River Watershed

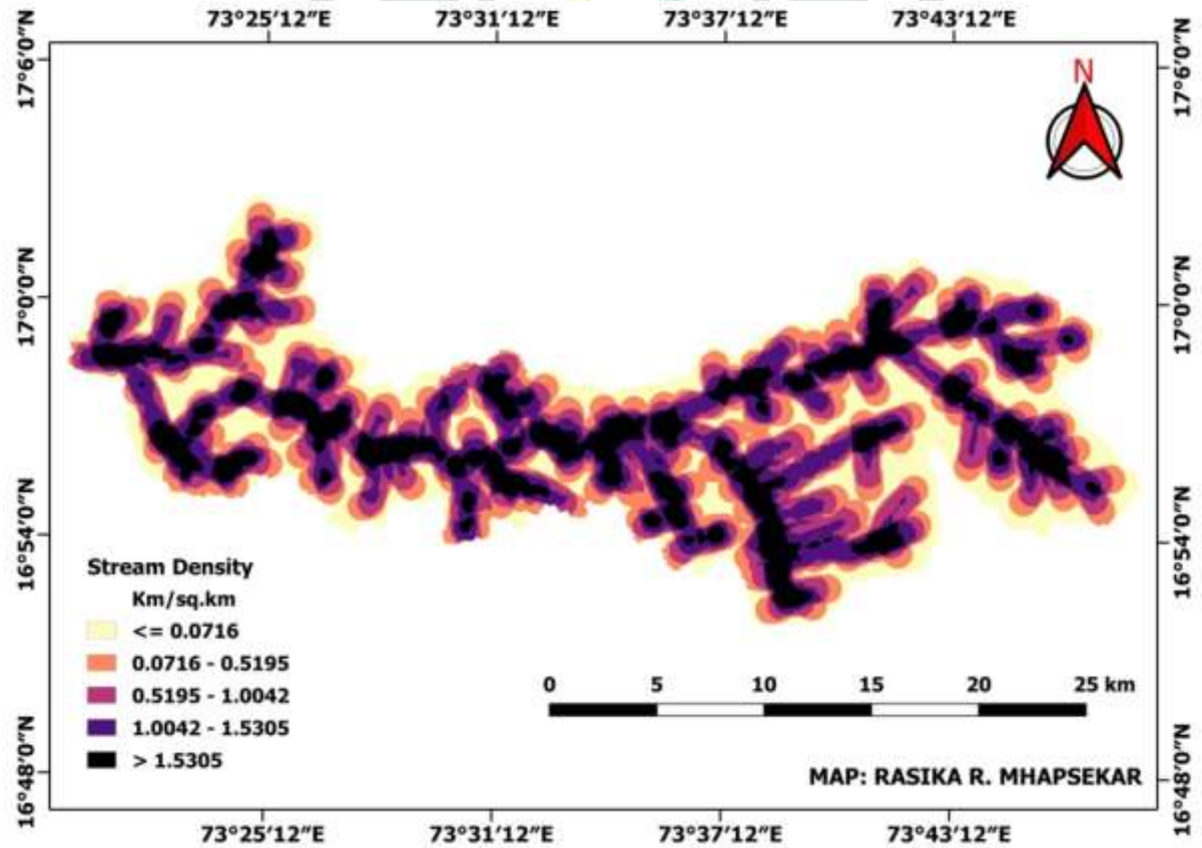

Figure 2: Stream Drainage Density of Kajali River Watershed

4.3 Relief Parameter Analysis

Relief of the watershed is the elevation difference between mouth and the highest point on the watershed perimeter and is expressed in meters. Basin relief values ranging from 0 to 200m for low relief, 200m to 500m for medium relief, 500 to 1000 for high relief values while values ranging greater than 1000 have very high relief. The maximum elevation of the study area is 914 m and Minimum elevation is 0 (i.e. mean sea level) so the basin relief of watershed is 914 m which is high. As relief possesses direct relationship with potential energy, denudation rate, amount of sediment that can be transported and discharge rate of a watershed, it is likely that the potential energy, denudation rate, the amount of sediment transported and discharge rate are likely to be higher in Kajali watershed as it had high basin relief. Relief ratio is the ratio between the total relief of the basin and its longest dimension parallel to the principal drainage line. It is also an indicator of intensity of erosion processes and sediment delivery rate of the basin. The relief ratio of study area is 0.015827 which Illustrates low relief, low erosion and more flatlands in watershed. Ruggedness number, the product of relief and drainage density is an index which reflects slope steepness and length it ranges between 0 to 1. It is observed that Kajali watershed had 0.783 ruggedness number value which describes that watershed had moderately rugged surface and is moderately susceptible to erosion.

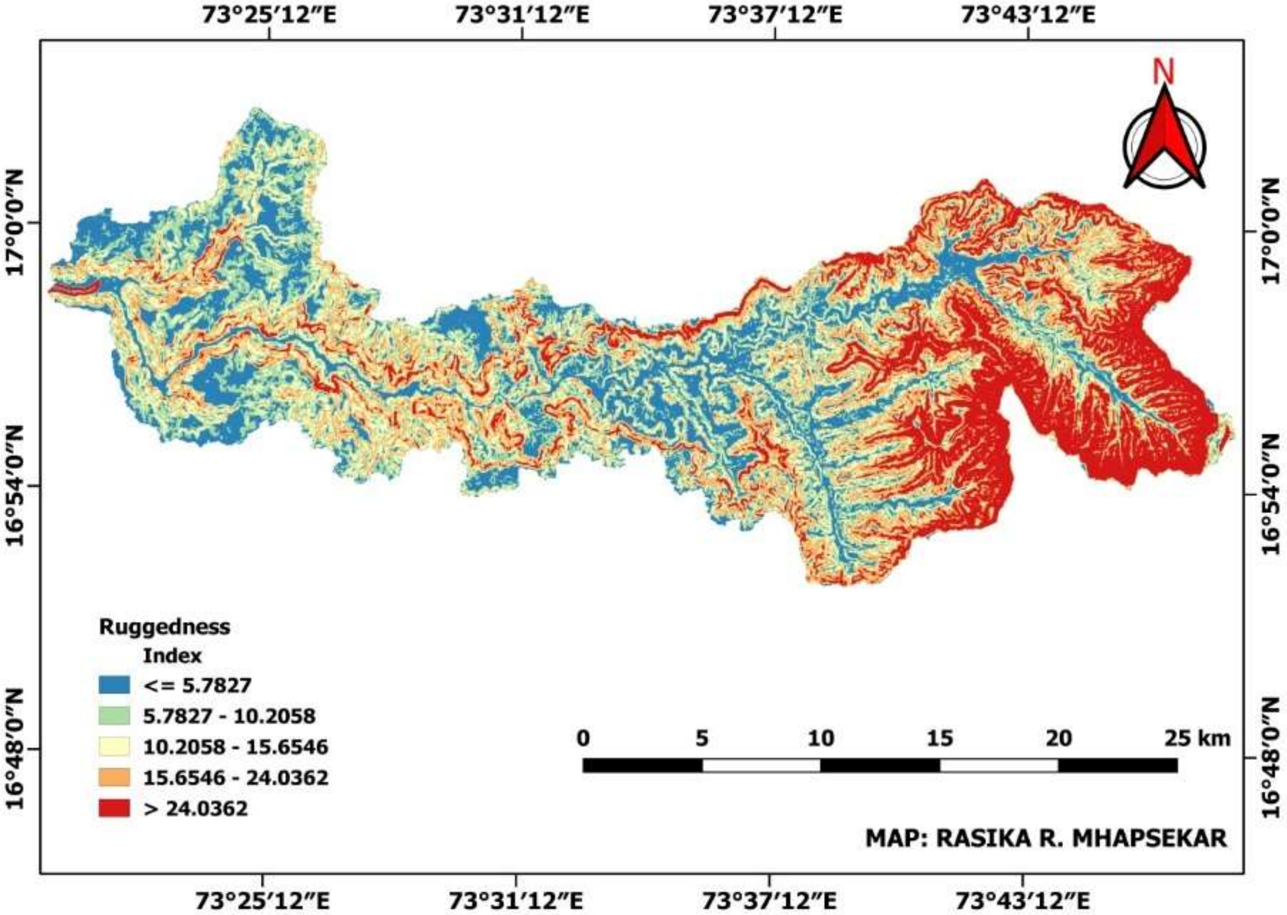

Figure 3: Ruggedness Index of Kajali River Watershed

5. Conclusions

- According to mean bifurcation ratio value (4.084811) of given watershed it indicates that the area has not suffered under geological structural disturbance.
- Low values of Drainage density (0.8568) and Drainage texture (1.7048) describe its permeable soil, very coarse drainage texture and relatively high relief areas.
- Stream frequency value (0.6098) also illustrates that the watershed area has permeable surface and high relief leads to slightly increase in runoff loss.
- Form factor Ff (0.1356), Elongation ratio Re (0.415) and Circulatory ratio Rc (0.109947) values reflect that the watershed area is of elongated shape and has high relief. Basin is less susceptible to flooding.
- Basin relief R (914 meter) Illustrates that watershed has moderate relief. Relief ratio (0.0158) describes more flatlands and low erosion and Ruggedness number Rn (0.7831) illustrates highly rugged surface of basin.
- Hydrologic behaviour of Kajali watershed describes that it has elongated basin with moderate relief, it is not susceptible to flooding. Basin has gentle slope and it is moderately susceptible to erosion.
- To prevent erosion, soil and water conservation practices should be performed in downstream areas.
- Due to prevalence of sedimentation in the watershed, relevant soil and water conservation practices related to channel maintenance should be performed to prevent silting of the riverbed.
- According to above analysis, watershed has low storage capacity and to improve it is suggested to perform below activities:
    - Growing more vegetation like trees, grasses and bunds can enhance groundwater.
    - Great efforts should be made to 'harvest' rainwater.
    - Efforts like 'watershed development projects' should be implemented in cities.
    - Small bunds can be built across streams to stop the flow of water.
- Since the runoff and basin relief are directly proportional to each other high value results high runoff. To prevent runoff conservative measures should be applied to the watershed like Check dams, Percolation ponds, Farm ponds, Rooftop rainwater harvesting, Contour farming, Contour trenches, etc.

6. ACKNOWLEDGMENT

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