Morphometric Analysis of the Tunga River Sub-catchment, Karnataka, India Using Remote Sensing and QGIS: Implications on Water Resource Allocation

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(Received on 10 October 2024; In final form on 14 August 2025)

DOI: *https://doi.org/10.58825/jog.2025.19.2.190*

Abstract: Tunga River Sub-catchment is situated in Western Ghats, Karnataka and has a humid climate. The qualitative morphometric analysis is significant to gauge the basin potential is essential for management of natural resource under increasing precipitation trends. Linear, areal and relief aspects are computed and evaluated using Quantum Geographical Information System (QGIS 3.28) plugins. Drainage network derived SRTM DEM 30m indicates Tunga River Sub-catchment is a 5th Order basin with sub-dendritic drainage network. Areal features such as Elongation ratio (0.51), Circularity ratio (0.31) and Form factor (0.20) indicates the basin is elongated and the time of concentration for present study is 12.23 hours. Low Drainage density (0.61 km/km^2) indicates that the basin is composed of permeable material having low to moderate relief. Low Infiltration number (0.15), high Length of overland flow (0.81) and high Constant of channel maintenance (1.62), indicate that there may be more opportunities for infiltration, potentially leading to higher groundwater recharge rates. Sub-catchment potential assessment using aspects such as Stream frequency and Drainage density in relationship between Bifurcation ratio ensures the catchment has high basin potential.

Keywords: Morphometric analysis, QGIS, **S**RTM DEM, Humid Catchment, Western Ghat

1. Introduction

Drainage Morphometry is a signature of basin hydrological response. Utilizing contemporary tools, Remote Sensing (RS) along with Geographic Information Systems (GIS) are extensively used by planners and policy makers to make wise decisions that save time and money (c.f. Meshram and Sharma, 2015). In forest dominated, humid catchments that are often inaccessible, this tool plays an important role in tackling major environmental challenges such as land degradation, unstable slope, flooding, landslides, and excessive surface runoff (Malik et al., 2019). Variation in precipitation events and land-use changes have in turn affected the morphometry of forest dominated humid catchments of Western Ghat, India (Nagamani and Bhagwat, 2024).

Morphometric aspects of a catchment offer comprehensive information about the lithology of the rock present beneath the drainage systems, their inter-relationship with the branching of stream network, chances of flood occurrence, surface runoff volume, and infiltration capacity (Nitheshnirmal et al., 2017). The open-source Digital Elevation Model (DEM) data products of various resolution from various satellite sensors (Bogale, 2021). RS and GIS approaches are successfully integrated to evaluate the basin's potential. (Bagwan and Gavali, 2021).

The present study employs a high-resolution DEM for morphometric evaluation that enhances the accuracy in extracting the streams, thereby increasing the accuracy of morphometric aspects computation. These features help to the basin's qualitative assessment of hydrological processes within the basin, that helps in locating highly sensitive sites to erosion through fluvial processes. Further, this information is crucial for formulating policies for water resources allocation (Prathapani et al., 2025).

2. Study Area

The River Tunga originates near Gangamoola (also known as Varahaparvatha) in the Chikmagalur district of Karnataka (Figure 1). This region, is a hotspot for biodiversity and is part of the Western Ghats. The river flows through the districts of Chikmagalur and Shivamogga (147 km long) before merging with the Bhadra River at Koodli and emerges as the Tungabhadra River. Basin relief for the Tunga Sub-catchment varies from 552m to 1659m from mean sea level (Figure 1). The Tunga River Sub-catchment (latitude: 14^0 00' 00"N and longitude: 75^0 39' 99" E), located in the Western Ghat, receives 1024 mm of average rainfall and mean temperature 26.7 °C annually. The relative humidity recorded in the Tunga River Sub-catchment ranges from 17 % to 92 %. The Sub-catchment is dominated by clay loam soil**.**

3. Methodology

3.1 Data collection

SRTM 30m resolution DEM *(Source:https://earthexplorer.usgs.gov, April 2024)* was imported into QGIS version 3.28 to delineate watersheds boundary and stream network.

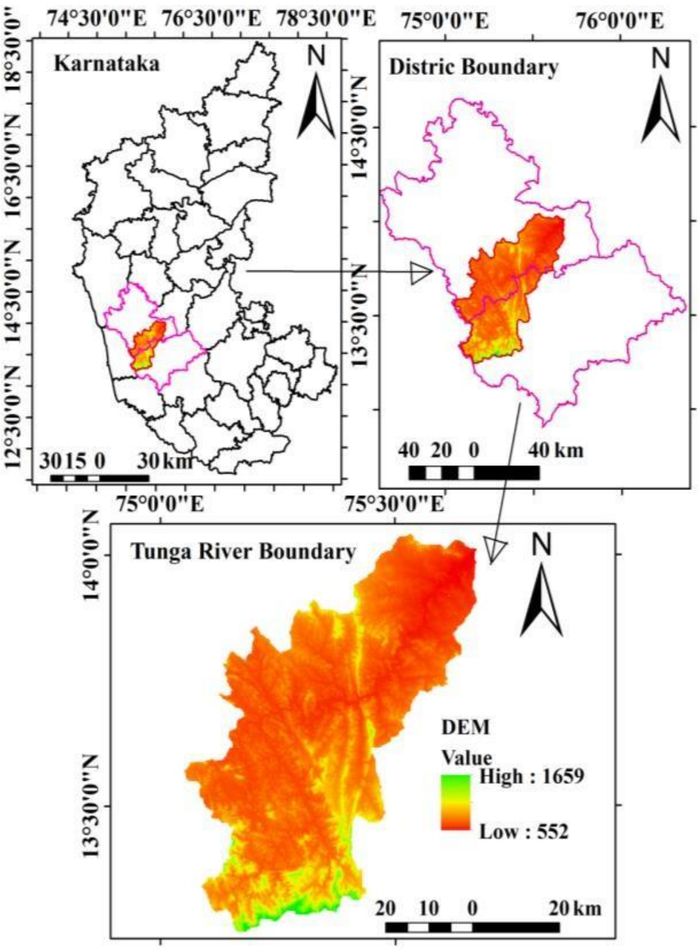


Figure 1. SRTM DEM 30m of the Tunga River sub catchment (source: https://earthexplorer.usgs.gov/)

3.2 Data processing

The Methodology outlines the step-by-step process for watershed delineation using QGIS (3.28) software, leveraging its various tools and plugins. This process includes pre-processing of DEM and preparing the necessary data obtained from various GIS data repositories. The DEM data was mosaiced and re-projected to WGS-1984/UTM zone 43N (EPSG: 32643). The Wang & Liu 2006, was used to fill sinks in the re-projected DEM. Flow Analysis includes generation of stream network and outlets resulted in delineated watersheds (Figure 2). Drainage order (Strahler, 1957) was calculated with a threshold of ≥6 to identify the main stream among smaller streams.

3.3 Data Analysis

Catchment geometry, length, and relief were determined by using raster tool in QGIS. Additional morphometric parameters were derived by applying respective formulae (Table 1.) in Microsoft Excel using the data obtained from QGIS (3.28)

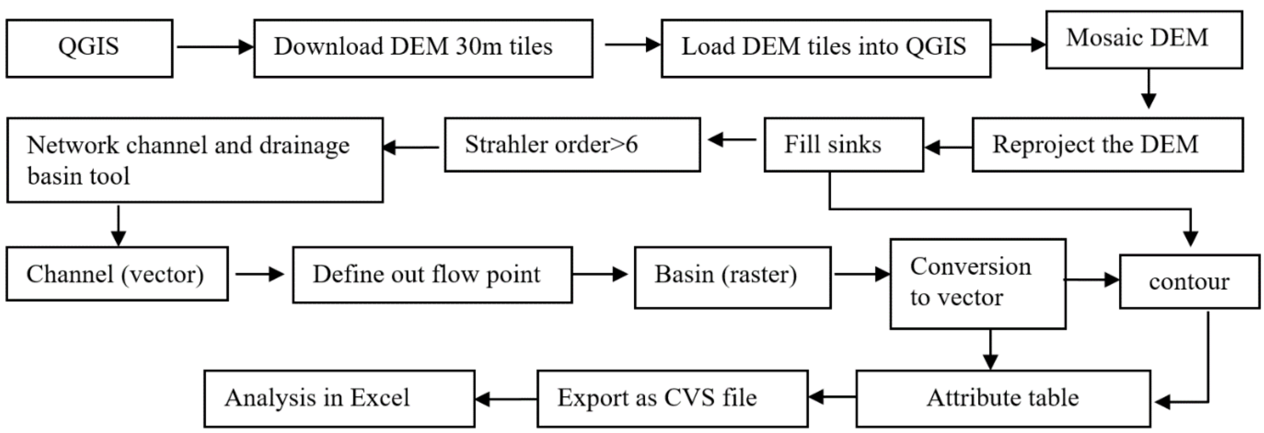


Figure 2. Methodological steps for processing of Morphometric Analysis for Tunga River Sub-catchment

4. Result and Discussion

4.1 Morphometry Analysis

Morphometric analysis provides qualitative assessment of hydrologic response for a catchment. It includes the quantification of catchment linear, aerial, relief aspects and ground slope that contributes to the basin as described by earlier studies (Rai et al., 2019; Bhagwat et al., 2011). The Soil characteristics such as water retention capacity, transmissivity, and permeability are interpretation using these parameters qualitatively (Romshoo et al., 2012). The geomorphology, soil, geology, and vegetation are important factors contributes to the drainage network pattern. Furthermore, runoff and land degradation conditions can be studied using morphometric analysis. Topography is the primary factor that determines flood inundation (Brasington and Richards, 1998). These are considered the key factor governing the runoff behavior within a sub-catchment. Similarly, for a more accurate evaluation of a catchment hydrology, morphological aspects are essential (Romshoo et al., 2012; Strahler 1957). The Tunga River drainage network shows dendritic to sub-dendritic pattern. In the current study, the drainage of basin was ranked using Hortons-Strahler's stream ordering technique (Horton, 1945). The stream network of the Tunga River Sub-catchment is dendric to sub-dendric (Figure 3).

Table 1. Methods adopted to Derive morphometric parameters

S. No.	Morphometric parameter	Methods	Value
1	Area of basin(A)	QGIS (Raster Calculator) km^2	2980.80
2	Basin perimeter(P)	QGIS (Raster Calculator) km	349.27
3	Basin length (L_b)	QGIS (Raster Calculator) km	121.84
4	Mean basin width (W_b)	QGIS (Raster Calculator) km	24.54
5	Maximum elevation (H)	QGIS (Raster Calculator) km	1659.00
6	Minimum elevation (h)	QGIS (Raster Calculator) km	552.00
7	Mean bifurcation ratio (R_{bm})	$R_{bm}=\sum R_b/n\times u$, Where, R_{bm}= Avarage of R_b	4.93
8	Stream order(u)	QGIS (channel network and drainage Basins tool)	5th order Sub-catchment
9	Drainage density (D_d)	$D_d=Lu/A$ where, L=Total length of all stream segments A=Area of basin	0.61
10	Stream frequency (F_s)	Fs=Nu/A where, Nu=Total length of all stream segments of all orders A=area of the basin	0.24
11	Texture ratio (T)	$T=N_{1/}P$ Where, N_1 = total number of all stream segments of 1st order P= Perimeter of the basin	1.65
12	Form factor (R_f)	$Rf = A/ L_b^2$ where, A=Area of the basin L_b= Basin length	0.20
13	Circulatory basin (R_c)	$R_c = 4\pi A/P^2$ where, A=area of basin P= perimeter of basin	0.30
14	Elongation ratio (R_e)	$Re=\sqrt{\frac{A}{\pi}}/L_b$ where, A=area of basin L_b =length of basin	3.89
15	Length of overland Flow (L_o)	$Lo=1/(2*D_d)$ where, D_d= Drainage density	0.30
16	Constant channel maintenance (C)	$C=1/D_d$ where, D_d= Drainage density	1.62
17	Lineament density	- (km/km^2)	0.06
18	Basin relief (B_h)	$B_h=H-h$ where, H= highest elevation points of the basin, h= lowest elevation points of the basin	832.00
19	Basin relief ratio (R_h)	$R_h= B_h/L_b$ where, Bh=Basin relief, L_b=Basin length	0.01
20	Relative relief (R_r)	$R_r= B_h/P$ Where, B_h= Basin relief, P= Basin perimeter	
21	Ruggedness number (Rn)	$Rn=(D_d*B_h)/1000$ Where, Bh= Basin relief, Dd= Drainage density	0.51
22	Time of concentration (Tc)	hrs	12.23
23	Infiltration number (If)	Dd*Fs	0.15

4.2 Linear parameters

4.2.1 Stream order (U): The Tunga River is 5th order basin (Figure 3.). Stream order is a determined by relative size of streams. A basin's principal river is the stream segment of nth order. The order of stream and river discharge are clearly correlated. Significantly more discharge is associated with a higher stream order compared to a lower stream order (Costa, 1987).

Stream number (Nu): Stream number is the total number of stream segments that correspond to each drainage basin order (Borkotoky et al., 2020; Lama and Maiti 2019; Rai et al., 2019). In a drainage, the expected number of streams network varies depending on the order (Chougale and Sapkale, 2017). The stream order and stream number have an inverse relation; that is, the higher the stream order, the lower the stream number, and the lower the stream order, the higher the stream number (Table 2) (Meshram and Sharma, 2015).

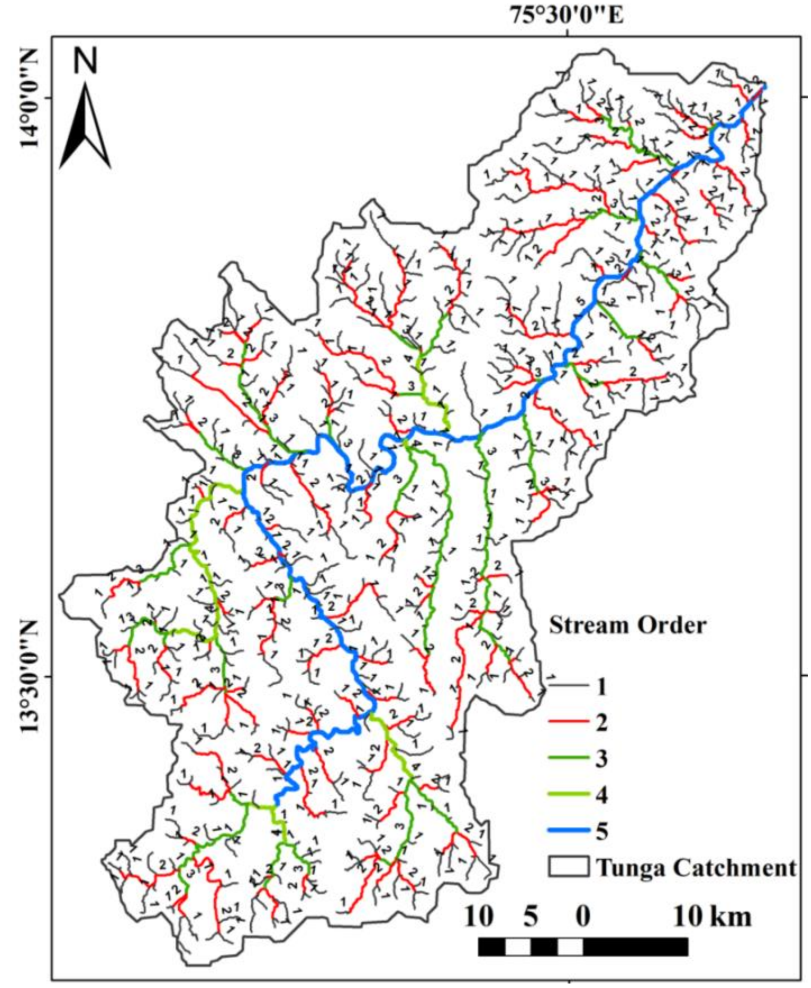


Figure 3. Horton's Stream order for the drainage Network for the Tunga River Sub-catchment

4.2.2 Stream length (L_u): According to Lama and Maiti (2019), stream length is the total of all stream segment lengths for a particular order. According to Iqbal et al., 2013, there is an inverse link between stream length and stream order: Higher the stream order, shorter the stream length, and lower the stream order, longer the stream length. Hydrological properties of bedrock and the extent of drainage are depicted by stream length (Lama and Maiti, 2019). The stream length is influenced by the permeability of the bed rock and other formations. Stream length of the Tunga River Sub-catchment for 1st, 2nd, 3rd, 4th and 5th stream order is 923.40, 486.70, 223.50, 58.30, and 145.70 km respectively (Table 2). As the order of streams increases, the overall stream length trend decrease from its maximum for first order. But Stream length for 4th order exhibits deviation from above condition this is due to Streams flowing from high elevations along steep gradients or changes in the surrounding rock could be the cause of this transformation.

4.2.3 Mean stream length (L_{sm}): It shows an inverse relationship with the order of the stream. Mean stream length of Tunga River Sub-catchment is determined as 1.60, 3.80, 7.98, 9.72 and 145.70 km for 1st, 2nd, 3rd, 4th and 5th order streams, respectively (Table 2).

4.2.4 Stream length ratio (R_L): Stream length ratio for the Tunga River sub-catchment is 0.53, 0.46, 0.26, 2.5 for 1st, 2nd, 3rd, and 4th order respectively (Table 2). In present study, the ratio between the orders area differs from one order to another. The number of stream segments of each order and the order number follow an inverse geometric sequence with the order number, according to the law of stream number (Horton, 1932). Typically, when the number of streams each order is plotted stream order using logarithmic regression, it produces a straight-line graph with minimal scatter. This law for the Tunga River Sub-catchment was confirmed by the regression plot (Figure 4). The higher number of 1st order streams indicate complex terrain and relatively resistant bedrock. Variations in basin hierarchy and dimensions are primarily governed by the physiographic and structural characteristics of region (c.f. Jasmin et al., 2012). 1st 2nd and 3rd are following the trends of Horton's law of stream length except 4th order stream. Shorter fourth order stream length indicated bedrock and formation are relatively permeable.

4.2.5 Bifurcation ratio (R_b): This is a dimensionless quantity. For the 1st, 2nd, 3rd and 4th orders were obtained as 4.2, 4.57, 4.67 and 6.00 respectively. The degree of integration of stream of various orders within the basin is indicated by these values Horton (1945) considered the bifurcation ratio as an index of relief and a measure of watershed dissection, particularly in areas with relatively homogeneous geology and absence of significant structural conformities. The bifurcation ratio typically ranges from 3.0 to 5.0. The bifurcation ratio is 4.94, indicating absence of structural disturbances (Table 2).

Table 2. Drainage Characteristics of the Tunga River sub-catchment

u	**N_u**	**L_u km**	**$R_b=\frac{Nu}{N_{U+1}}$**	**$L_{sm}=\frac{Lu}{Nu}$ km**	**$R_{Lsm}=\frac{Lu}{Lu-1}$**
1	578	923.4		1.60	
2	128	486.7	4.52	3.80	0.53
3	28	223.5	4.57	7.98	0.46
4	6	58.3	4.67	9.72	0.26
5	1	145.7	6.00	145.70	2.50
Total	**741**	**1837.6**	**Mean=4.94**		

Note: *u is stream Order, N_u is streams number, L_u is total Stream length, R_b is Bifurcation ratio, L_{sm} is mean stream length and R_{sm} is mean stream length ratio.*

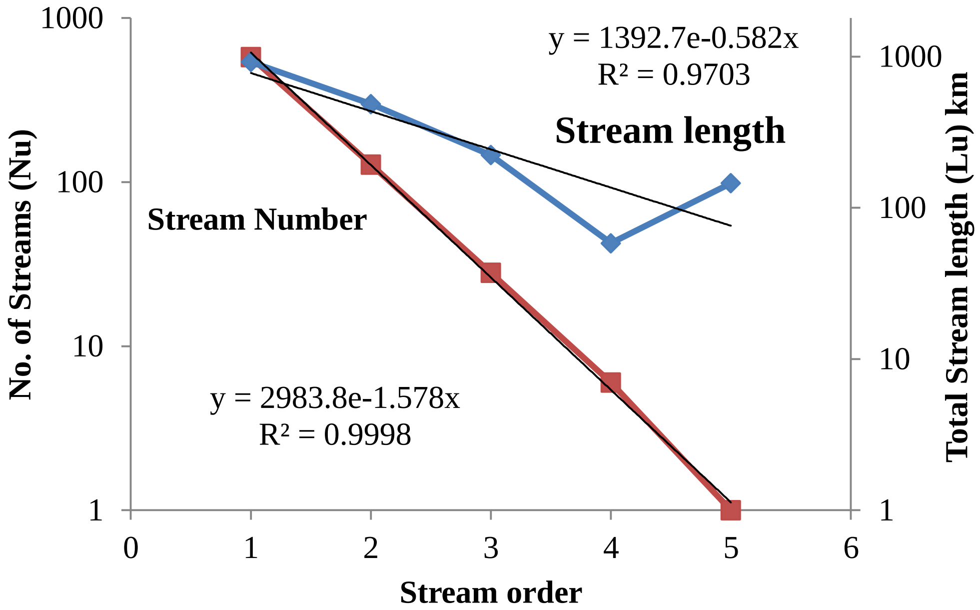


Figure 4. Plot of stream order v/s stream number of Tunga River sub-catchment

4.3 Aerial parameters

4.3.1 Drainage density (D_d): A low drainage density indicates coarse texture, while a fine drainage texture is indicated by high drainage density. Drainage density is also directly related to the severity of erosion processes within a watershed (Ahmed et al., 2018). In areas with poor impermeable underlying material, little vegetation, and mountainous relief, the drainage density is higher. Low drainage density (0.616 km/km^2) indicates semipervious soil with vegetation and less relief (Table 1).

4.3.2 Stream frequency (Fs): A low stream frequency (0.24) (Table 1) indicates higher infiltration capacity, which enhances groundwater recharge potential, while high stream frequency reflects limited infiltration and greater surface flow (Sreedevi et al., 2004). It is primarily affected by the permeability of subsurface materials, relief, vegetation cover, rainfall quantity and type, and rock structure. It also has impact on the basin texture.

4.3.3 Circularity ratio (Rc): It is an important area-based morphometric measure that illustrates phases of a watershed's evolution (Adhikari, 2020). The old, mature, and youthful stages of a watershed are indicated by high, medium, and low circulation ratios. According to (Sujay and Hegde, 2024; Choudhari et al., 2018) the geological structure, basin slope, climate, relief, and land cover all affect a drainage basin's circulating ratio. The circularity ratio of the Tunga River Sub-Catchment is 0.307 (Table 1), indicating Su-catchment is elongated in shape and youthful stage.

4.3.4 Form factor (Rf): It is area-specific morphometric aspect of a drainage basin (Horton, 1945). The form factor is a measurement of a drainage basin's circularity. According to Choudhari et al., 2018, the basin gets more circular as its form factor value increases and becomes more elongated when it decreases. A larger form factor value denotes a wider basin, where as a lower value indicates a narrower basin (Chandrashekar et al., 2015). Drainage basins with a high form factor are characterized by intense peak discharge occurring over shorter time spans. Low form factor (0.20) for the Tunga River results in an elongated Sub-catchment with a low peak (Table 1) and exhibits higher water retention capacity because of its larger surface area in relation to its perimeter.

4.3.5 Elongation ratio (Re): More circular basin, as indicated by a greater elongation ratio value (Schumn, 1956). More elongation, high filtration, and less runoff are observed in basins with lower elongation ratio values (Choudhari et al., 2018). The Re values are classified into round (>0.9), oval (0.9-0.8), and elongated (<0.7) (Nyamathi and Kakkalameli, 2018). Elongation ratio for Tunga River Sub-Catchment is 0.51 (Table 1), which indicating the basin is elongated and hence higher potential for recharge.

4.3.6 Texture ratio (T): It is primarily determined by the type of rock, the relief of terrain, the climate, the amount of rainfall, and the stage at which the river has developed (Horton, 1945). High texture ratio indicates the lower rock permeability and a higher discharge. The texture ratio calculated for Tunga River sub-catchment is 1.65 (Table 1). Indicates moderate permeability.

4.3.7 Length of overland flow (Lo): The amount of water that flows above ground before condensing into distinct stream segments is referred to as "length." It establishes the drainage basin's erosion threshold. According to Horton (1945). The average channel slope and is inversely related (Ramaiah et al., 2012). A drainage basin's hydrological and hydrographic evolution is governed by overland flow length (Altaf et al., 2023). When the overland flow is for longer duration, it has a greater length indicating a well-developed drainage system typically associated with steeper slopes. Conversely, the shorter the flow length, which allows surface runoff quickly enter the stream. Its length is categorized as Low value (<0.3), moderate value (0.2-0.3), and high value (>0.3) are the three categories under which length of overland flow is divided. The Tunga River Sub-catchment over land flow is 0.308km (Table 1), which shows that terrain has percolation capacity or if there are substantial vegetative cover and soil infiltration capacity, the water may infiltrate into the ground rather than contributing significantly to surface runoff.

4.3.8 Constant channel maintenance (C): It is the inverse of drainage density, and has dimension of length (Schumn, 1956). Channel maintenance can be high and drainage density should be low in area with resistant rock types, high permeability surfaces, or strong forest cover (Bhagwat et al., 2011). Conversely, areas with limited soil permeability and infiltration, weak rock types, or little to no vegetation should have high drainage density and low channel maintenance constants. The constant channel maintenance in this present study was 1.62 (Table 1), suggesting good infiltration, high permeability, and good vegetal cover.

Time of concentration (Tc): it is defined as the maximum time taken by a drop of water to travel from the most distant point of the watershed divide to the watershed outlet (Vittala et al., 2004). It is applied in estimating the peak discharge of a watershed, with the Kirpich formula (Equation 1) commonly used to compute the time of concentration. The watershed's longest watercourse (L), average slope (S), and a coefficient representing the kind of groundcover are necessary inputs for the determination of the concentration time.

$$Tc=0.0662*L^{\wedge 0.77}*S^{(-0.305)} \qquad (1)$$

The time of concentration for present study is 12.231 hours (Table 1), which indicating there may be more opportunities for infiltration, potentially leading to higher groundwater recharge rates.

4.3.9 Infiltration number (If): It is function of drainage density and stream frequency. These parameters are representing a function of these two parameters and indicate the basin infiltration properties (Manu & Anirudhan, 2008). There is a direct correlation between higher infiltration number corresponds to greater runoff and lower infiltration. Stronger infiltration and very little runoff are implied by lower infiltration values (<6) in watersheds. In watersheds, moderate infiltration and moderate runoff potential are indicated by infiltration values of 7-10. Watersheds with a high infiltration number (>10) have very little infiltration and a significant potential for runoff. Infiltration number for Tunga River sub-catchment is 0.153 (Table 1), indicating the Sub-catchment has stronger infiltration.

4.4 Relief parameters

Relief parameter includes basin relief, basin relief ratio, and ruggedness number.

4.4.1 Basin relief (Br): Basin relief represents the vertical difference between the maximum elevation and minimum elevation within the basin. The basin ration for the present study was determined as 832 m (Table 1).

4.4.2 Basin relief ratio (Rh): Basin relief ration assesses the overall (average) slope of a drainage basin and is considered one of the finest indicators of erosion (Hajam et al. 2013; Ahmed et al. 2018). It is quantity without dimensions. The relief ratio for this study is 0.01 (Table 1), which suggests that low to moderate relief would indicate a lower susceptibility to soil erosion. This is expressed as a dimensionless quantity. For the current study relief ratio is 0.01 (Table 1), indicates low to moderate relief would indicate less soil erosion susceptibility.

4.4.3 Ruggedness number (R_n): It expresses the combined effect of drainage density (D_d) and basin relief (B_h), with both parameters expressed in identical units. When all factors are high value and the slope is both steep and long, the ruggedness number (R_n) will be extremely high (Strahler, 1957). Higher ruggedness number value indicates a greater susceptibility of soil erosion. The Tunga River Sub-Catchment of ruggedness number value is 0.51 and indicating terrain is less susceptible to erosion (Table 1). This suggests dense vegetation in the basin**.**

4.4.4 Lineament density

Lineament are geological formations are easily visible in satellite images and can be either curved or straight. Certain features of these lineaments relate to highlighting joints, faults, or boundaries between lithologic or stratigraphic deposits. Taken together, the lineament per unit area equal the lineament density. If the lineaments are denser, more percolation may occur. Figure 5 shows the lineament density in the Tunga River sub-catchment. Then Tunga River sub catchment is 0.05 km/km^2 (Figure 5.), which indicates moderate groundwater availability. They are thought to represent potential locations for groundwater percolation and frequently.

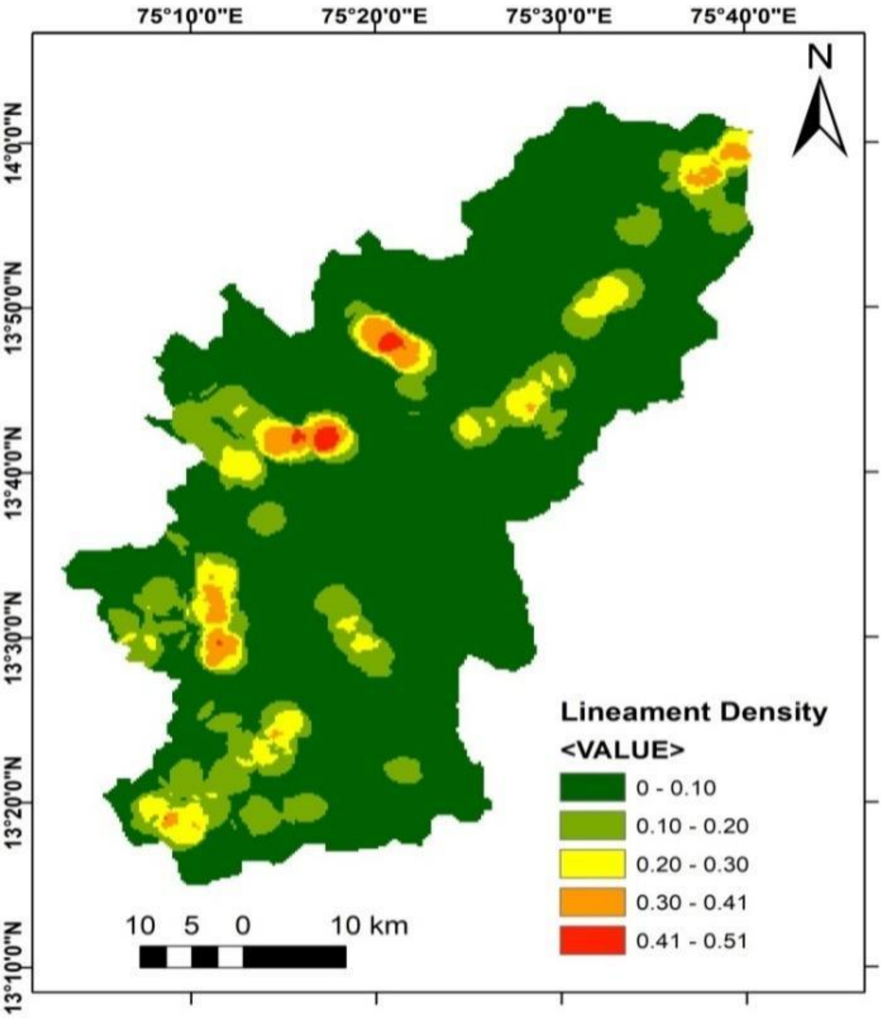
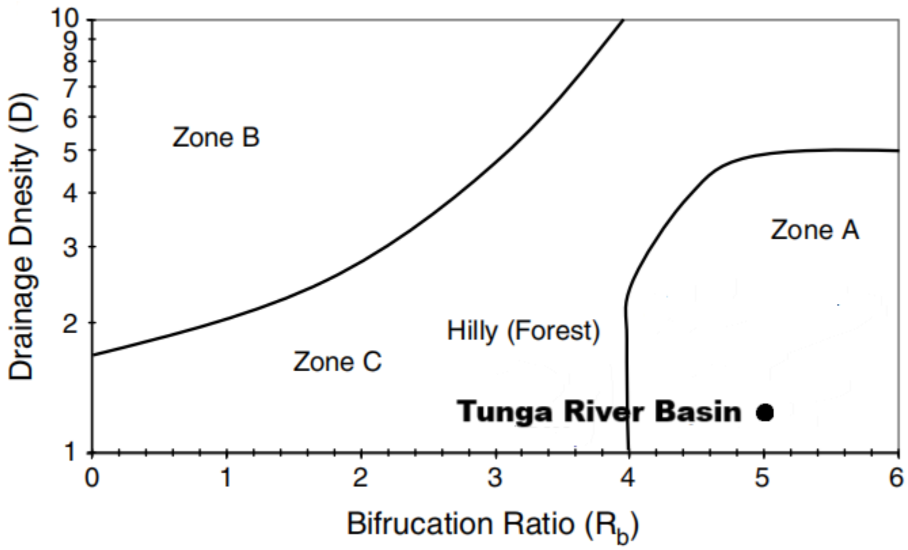


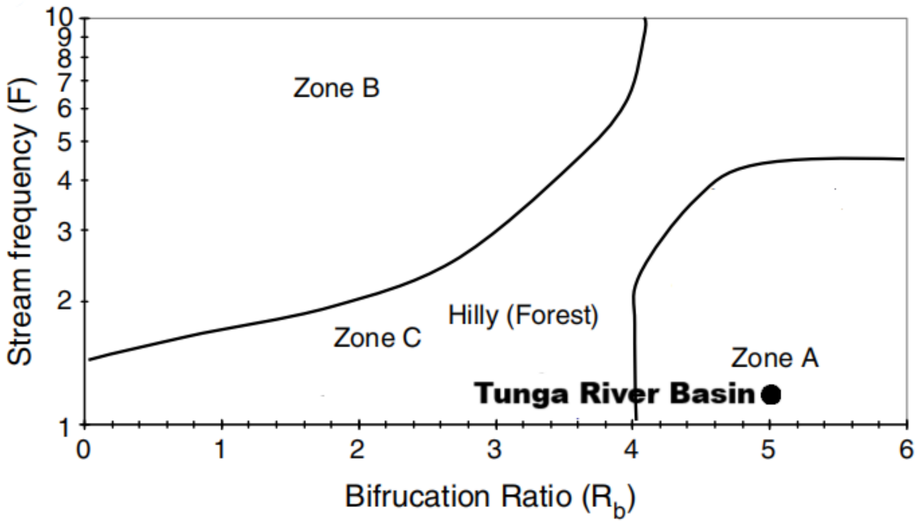
Figure 5. Lineament density map of the Tunga River sub-catchment.

4.5 Basin potential

The Tunga River Sub-catchment is qualitatively determined by the relationship between bifurcation ratio, drainage density, and stream frequency. Since each plots have two curves, the region is divided into three zones on semi-log graph (Figure 6a, 6b). Semi-log plot for Tunga River Sub-catchment (D_d Vs R_b and F_s Vs R_b), characterized by high water recharge property (zone A). The relation is established graphically, thus compared to dedicated illustrations obtained by Bhagwat et al. 2011 for this purpose.



(a)



(b)

Figure 6. Potential of the Tunga River sub catchment based on morphology parameter. Zone A: High recharge property (a) and (b). Zone A: has high recharge property Zone B: Has low recharge property Zone c: has the moderate recharge property (Bhagwat et al., 2011; Patil and Bhagwat et al., 2023)

5. Conclusions

The basin morphometric aspects were categorized into linear, areal and relief using QGIS (3.28) software. The Tunga River Sub-Catchment has elongated shape, low mean bifurcation ratio (4.93) and low stream frequency (0.24) that indicates, the terrain is highly permeable. Low drainage density (0.61) and coarse texture (1.65) typically suggest that the water in an area has limited opportunities to drain away, it means indicating that there may be greater chance of ground water accumulation. Further, time of concentration (12.23), lineament density (0.056) and lower the infiltration number (0.15) indicates fewer run-offs and high infiltration. The basin has a high possibility of ground water recharge. The study's findings will be helpful in categorizing river basins for future sustainable management of water resources, as well as determining the suitable sites for constructing water-conservation structure like check dams, percolation tanks, and artificial groundwater recharge system.

Acknowledgments

For providing the facilities necessary to conduct the study, the authors sincerely express their gratitude to Visvesvaraya Technological University, Belagavi and

University B.D.T college of Engineering, Davangere, A constituent college of VTU university, Department of Studies in Civil Engineering, Davanagere Karnataka, India for providing facility to carry out the study. The authors grate the USGS Earth Explorer, US for Providing high resolution STRM 30m resolution DEM for Morphometric analysis of Tunga River Sub-catchment.

References

Adhikari, S. (2020). Morphometric analysis of a drainage basin: A study of Ghatganga River, Bajhang District, Nepal. The Geographic Base, 7, 127–144.

Ahmed, R., H. Sajjad and I. Husain (2018). Morphometric parameters-based prioritization of sub-watersheds using fuzzy analytical hierarchy process: A case study of Lower Barpani watershed, India. Natural Resources Research, 27, 67–75.

Alemayethu, A. and A. Tesfaye (2024). The morphometric investigation of the Gelda watershed in Lake Tana sub-basin. Modeling Earth Systems and Environment, 10(3), 4207–4222.

Altaf, F., G. Meraj and S. A. Romshoo (2023). Morphometric analysis to infer hydrological behavior of Lidder watershed, western Himalaya, India. Geography Journal, 1, 178021.

Asode, A. N., A. Sreenivasa and T. K. Lakkundi (2016). Quantitative morphometric analysis in the hard rock Hirehalla sub-basin, Bellary and Davanagere Districts, Karnataka, India using RS and GIS. Arabian Journal of Geosciences, 9(5), 381.

Bagwan, W. A. and R. S. Gavali (2021). An integrated approach for the prioritization of sub-watersheds in the Urmodi River catchment (India) for soil conservation using morphometric and land use/land cover (LULC) factors. Journal of Sedimentary Environments, 6(1), 39–56.

Bhagwat, T. N., A. Shetty and V. S. Hegde (2011). Spatial variation in drainage characteristics and geomorphic instantaneous unit hydrograph (GIUH); implications for watershed management – A case study of the Varada River basin, Northern Karnataka. Catena, 87(1), 52–59.

Bhagwat, T. N., V. S. Hegde and A. Shetty (2018). Application of remote sensing and GIS for identification of potential groundwater recharge sites in semi-arid regions of hard-rock terrain, north Karnataka, South India. Sustainable Water Resources Management, 4(4), 1063–1076.

Bogale, A. (2021). Morphometric analysis of a drainage basin using geographical information system in Gilgel Abay watershed, Lake Tana Basin, upper Blue Nile Basin, Ethiopia. Applied Water Science, 11(7), 122.

Borkotoky, K., S. Chetia and S. Medhi (2020). Many facets of a river basin: Morphometric characteristics of Barnadi River Basin, Assam using GIS and remote sensing techniques. International Journal of Advanced Science and Technology, 29, 3286–3297.

Brasington, J. and K. Richards (1998). Interactions between model predictions, parameters, and DTM scales for TOPMODEL. Computers and Geosciences, 24(4), 299–314.

Chanapathi, T. and S. Thatikonda (2020). Investigating the impact of climate and land use/land cover changes on hydrological predictions over the Krishna River basin under present and future scenarios. Science of the Total Environment, 721, 137736.

Chandrashekar, H., K. V. Lokesh and M. Sameena (2015). GIS-based morphometric analysis of two reservoir catchments of Arkavati River, Ramanagaram District, Karnataka. Aquatic Procedia, 4, 1345–1353.

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

Chougale, S. S. and J. B. Sapkale (2017). Morphometric analysis of Kadvi River basin, Maharashtra using geospatial techniques. Current World Environment, 12, 635–645.

Costa, J. E. (1987). Hydraulics and basin morphometry of the largest flash floods in the conterminous United States. Journal of Hydrology, 93(3–4), 313–338.

Hajam, R. A., A. Hamid and S. Bhat (2013). Application of morphometric analysis for geo-hydrological studies using geo-spatial technology – A case study of Vishav drainage basin. Hydrology: Current Research, 4(3), 1–12.

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

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

Iqbal, M., H. Sajjad and F. A. Bhat (2013). Morphometric analysis of Shaliganga sub-catchment, Kashmir Valley, India using geographical information system. International Journal of Engineering Trends and Technology, 4(1), 10–21.

Ismail, M., H. Singh, I. Farooq and N. Yousuf (2022). Quantitative morphometric analysis of Veshav and Rembi Ara watersheds, India, using Quantum GIS. Applied Geomatics, 14(2), 119–134.

Jasmin, I. and P. Mallikarjuna (2012). Morphometric analysis of Araniar River Basin using remote sensing and GIS in the assessment of groundwater potential. Arabian Journal of Geosciences, 6(10), 3683–3692.

Lama, S. and R. Maiti (2019). Morphometric analysis of Chel River basin, West Bengal, India, using geographic information system. Earth Science India, 12.