Morphometric analysis of Hirehalla Sub-basin of Malaprabha River, Northern Karnataka using geoinformatics techniques

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Abstract: In the present study, basin morphometry of Hirehalla Sub-basin of Bagalkote District, Karnataka was carried out using remote sensing and geoinformatics techniques. Delineation and calculation of various morphometric parameters of the sub-basin was done in GIS environment. The study was categorized into– Linear, Aerial and Relief aspects. Result obtained from morphometric analysis confirms the highest order of fifth and showing sub-dendritic to dendritic drainage pattern. Values of shape parameters- form factor (0.16), elongation ratio (0.45) and circulatory ratio (0.38), suggests the sub-basin to be elongated in shape. Average bifurcation ratio value (Rb=3.34), indicates the influence of geomorphic features on the basin. From the values of Stream frequency (1.36) and drainage density (1.27) it indicates, permeable subsurface and low relief. Drainage texture value (1.74) suggests the basin is coarse. In addition, a low value of ruggedness number indicates the resistance of sub-basin to erosion.

Keywords: Hirehalla Sub-basin, Morphometric analysis, Drainage density, Bifurcation ratio, RS & GIS, Karnataka

1. Introduction

Morphometry is the measurement and mathematical analysis of the configuration of the Earth's surface, shape and dimension of its landforms (Clarke, 1966; Agarwal, 1998; Reddy et al., 2004). Morphometric analysis helps in understanding the original gradient or unevenness of rock hardness, structural limits, recent diastrophism, and lithological and geomorphological history of the catchment (Strahler, 1957; Morisawa, 1985). The quantification of drainage network and system is vital in river basin studies as it helps in related investigations- to assess the groundwater potential, surface and groundwater resource management, and environmental assessment (Strahler, 1964; Kudnar and Rajasekhar, 2019). Basin morphometry was first studied by Horton (1932, 1945). The morphometric analysis includes describing linear, aerial and relief features present within a basin (Nautiyal, 1994; Nag and Chakraborty, 2003; Fenta et al., 2017). These morphometric aspects have been studied using remote sensing and topographical maps (Mesa, 2006; Singh et al., 2013).

The hydrological setup of the exposed rocks within a watershed can be determined through quantitative morphometric study of the watershed. A basin's drainage map act as a good indicator of the permeability of rocks and their interrelationship between rock types, structures and their hydrological status (Magesh et al., 2013; Sreedevi et al., 2013). Stream network of drainage basin show temporal and spatial changes. Such runoff patterns significantly alter hydrologic systems, such as stream discharge, suspended sediments, dissolved solids and litter, and catchment characteristics (Bogale, 2021). Watersheds, catchments, and drainage basins serve as the fundamental administrative entities for managing the conservation of natural resources. The idea of basin control deals with the connections between lowlands, uplands, geomorphology, land use, soil, and slope. In watershed management, water and soil fortification is the chief issue in demarcating watersheds (Chandrashekar et al., 2015; Siddhiraju et al., 2020).

Morphometric analysis of the basin has been done with various objectives. Many researchers throughout the world have worked on drainage basins of different geologic and geomorphic regimes such as- *to understand the role of geology in influencing the drainage network of a basin* (Krishnamurthy et al., 1996; Sameena et al., 2009; Dubey et al., 2015). *Quantification and prioritization of watershed and sub-watershed* (Biswas et al., 1999; Hajam et al., 2013; Odiji et al., 2021). Assessment of potential flood risk and flood control were studied by Vandana et al., 2013; Withanage et al., 2015; Asode et al., 2016. However, over the last two decades or so before the emergence of science of RS and GIS, delineation of hydrological characteristics of a watershed can be achieved using conventional techniques and topographical maps (Panda et al., 2019). Further, in recent times, studies related to not only the assessment of various terrain and morphometric parameters of the drainage basins but agricultural, land use/land cover, climate change, recharge studies etc are all mostly done using the capabilities of RS and GIS, as they provide a flexible environment and powerful tools to manipulate and analyse spatial data.
In order to investigate the input of landuse and agriculture as well as climate change in Indonesia's Upper Brantas

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Basin, Setyorini et al., (2017) used GIS tools. For managing the water resources of Lower Kosi River Basin, Rai et al., (2017) performed morphometric analysis using RS data. Harsha et al., (2019) evaluated the morphometry and hypsometry of the Arkavathy River Basin in South India using the capabilities of RS and GIS. Mahala (2019) using ASTER data and GIS tools studied the hydro-morphological characteristics of Kosi and Kangsabati River Basin. Arefin and Alam (2020) applied RS and GIS techniques for water resource management of Dhaka City, Bangladesh. For the Mississippi Delta agricultural watershed, Risal et al (2020) used LULC data to investigate changes in surface water flows, sediment, and nutrient yield due to seasonal changes in land use and land cover. Ramachandra et al., (2020) identified potential groundwater zones in the western part of Cuddapah Basin with the aid of geospatial techniques.

Therefore, the investigation carried out using toposheet, remote sensing and GIS tools is mainly focused on assessing basin morphometric characters of Hirehalla Sub-basin of Malaprabha River. Further, in order to analyze the characteristics of various morphometric parameters which are necessary for better planning of soil and water conservation, different parameters have been calculated by means of a mathematical calculation.

2. Study area

The present study, Hirehalla Sub-basin forms part of Bagalkote District, Karnataka. Hirehalla Sub-basin is one of the tributaries of River Malaprabha which in turn is tributary of majorly flowing Krishna River. The Sub-basin is covered in Survey of India (SOI) toposheets numbering–47P/08; 47P/12; 47P/16; 48M/09 and 48M/13 and is geographically bounded between 74º 30' to 75º 15' N Longitudes and 15º 45' to 16º 15' E Latitudes and covers aerially an area of 288 Km^2 (Figure 1). The Sub-basin is connected with all seasoned roads. Physiographically, the study area is part of the Northern Plains with varied topography. Major soil types include a variety of red and black soil (CGWB, 2011). Geologically, the study area is comprised of arenites, basalts, granites, limestones and shale (Figure 2).

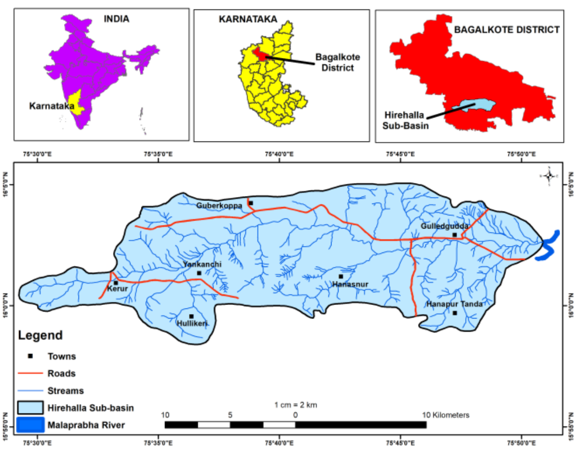

Figure 1. Location map of the study area

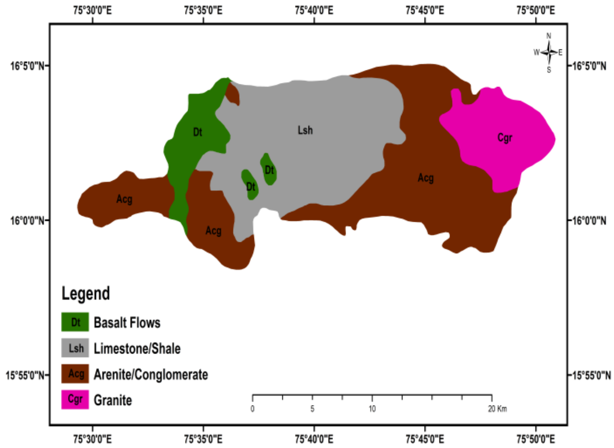

Figure 2. Geological map of the study area (After GSI, 2005)

3. Materials and methods

In this study, the boundary of Hirehalla Sub-basin has been demarcated from Survey of India toposheets numbered- 47P/08, 47P/12, 47P/16, 48M/09 and 48M/13 of 1:50,000 scale. Before demarcation, the toposheets were georeferenced using ground control points then rectified and projected in geographic projection, and re-projected into Universal Transverse Mercator (UTM) projection, WGS 1984, Zone 43 North datum. Table 1 shows the list of Morphometric parameters and their formulae and, the flowchart for the methodology used in this study is shown in figure 3. Its streams were manually delineated and digitized using ArcGIS version 10.3 software. The ordering of streams was done as per Strahler's system (Strahler, 1957). The drainage map of the sub-basin is shown in figure 4. Shuttle Radar Topography Mission-Digital Elevation Model (SRTM-DEM) data sets of one arc-second (30m) resolution is used in the present study. Spatial analyst tools were used to extract the DEM of the sub-basin. SRTM-DEM data used can be freely downloadable from the USGS Earth Explorer website. This data is then brought into the GIS environment and, slope, topographic elevation and contour maps of the basin are prepared. The study was classified into- linear, aerial and relief aspects. Morphometric parameters such as- stream order, stream number, bifurcation ratio were manually calculated whereas parameters such as stream length, stream frequency, drainage density, shape and, relief parameters were computed using the capabilities of ArcGISv10.3. The geological map of the study area was prepared from District Resource Map of Vijayapur district (then Bagalkote part of Vijayapur) published by the Geological Survey of India in 2005.

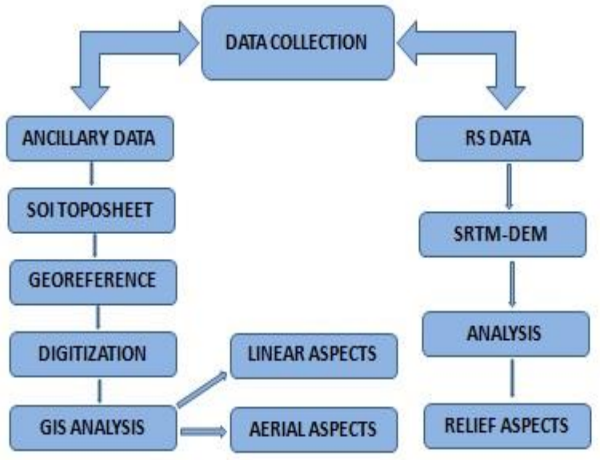

Figure 3. Flowchart of the methodology adopted

Table 1. Standard morphometric parameters and its computational formulae

Sl. No.	Morphometric Parameters	Formula/Definition	Reference
Linear aspects			
1	Stream Order	Hierarchical Rank	Strahler, 1964
2	Stream Number	Total number of stream segments of the order 'u'	Strahler, 1957
3	Bifurcation Ratio	$R_b=N_u/N_{(u+1)}$ where N_u=Total number of stream segments of the order 'u', and $N_{(u+1)}$ = Number of stream segments of the next higher order	Schumm, 1956
4	Stream Length	Total length of the stream segments of that particular order	Horton, 1945
5	Mean Stream Length	$Lsm=\sum L_u/N_u$ where L_u = Total length of the stream segments of that particular order N_u =Total number of stream segments of the order 'u'	Strahler, 1964
6	Stream Length Ratio	$R_l=L_u/L_{(u-1)}$ where L_u= The mean length of all stream segments of a given order (u), and $L_{(u-1)}$ = The mean length of all stream segments of one order less to given order(u)	Horton, 1945
7	Length of Overland Flow	$L_g=1/2D_d$ where D_d = Drainage density of basin	Horton, 1945
Areal aspects			
8	Form Factor	$F_f=A/L_b^2$ where A=Area of the basin (km^2), and L_b=Basin length (km)	Horton, 1932 & 1945
9	Circulatory Ratio	$R_c=4\pi A/P^2$ where A=Area of the basin (km^2), and P=Perimeter of basin (km)	Miller, 1953 & Strahler, 1964
10	Elongation Ratio	$R_e=D/L_b=1.128\sqrt{A}/L_b$ where D=Diameter of a circle of the same area(A) as the basin, A=Area of basin (km^2), and L_b=Basin length	Schumm, 1956
11	Drainage Density	$D_d=\sum L_u/A$ where L_u=Total length of the stream segments of that particular order, and A=Area of the basin (km^2)	Horton, 1932
12	Stream Frequency	$F_s=\sum N_u/A$ where N_u=Total number of stream segments of the order 'u', and A=Area of the basin (km^2)	Horton, 1932
13	Drainage Texture	$T=D_d*F_s$ where D_d=drainage density, and F_s=Stream frequency	Horton, 1945
14	Constant of Channel Maintenance	$C=1/D_d$ where D_d =Drainage density of basin	Schumm, 1956
Relief aspects			
15	Basin Relief	R=(Maximum - Minimum) Elevation	Hadley & Schumm, 1961
16	Relief Ratio	$R_r=R/L$ where R=Basin relief, and L=Basin Length	Schumm, 1956
17	Ruggedness Number	$R_n=R*D_d$ where R=Basin relief, and D_d =Drainage density of basin	Strahler, 1958

4. Results and discussion

4.1 Linear Aspects

4.1.1 Stream order and Stream number

The stream ordering method was first introduced by Horton (1932), which was subsequently modified by Strahler (1957) and is one of the most widely used methods for ranking streams. In the present study Strahler's method of stream ordering is used, where the smallest finger tip tributaries are designated as first order stream. When two such first order streams intersect, a stream of second order is developed. Further, a second order stream is created when two of these first orders meet and, stream of order third is formed when two streams of order two meets and so on. From the above, the sub-basin is found to be in the highest order of five (Table 2). According to Horton (1945), an inverse geometric sequence with an order number is formed by the number of stream segments in each order. In the present study, frequency of stream numbers is highest in the first order streams. It is also noted that with increasing stream order the frequency of stream number decreases (Table 2; Figure 6). This dominant first order streams in the sub-basin imply hilly terrain and compact nature of bed rock lithology (Magesh et al., 2013).

4.1.2 Stream length

Stream length (Lu) is a dimensional property used to understand the characteristic size of the components of a drainage network. Generally, where rock formations are permeable, a smaller number of relatively longer streams are formed, whereas a larger number of smaller streams are formed where rock formations are less permeable (Pakhmode et al., 2003; Subba rao, 2008). In the present study, ESRI ArcGIS version 10.3 software is used to measure the stream length of the basin from river mouth to the drainage divide. The measured stream length of sub-basin was in line with the law proposed by Horton (1945). From the study, it was observed that the total length of the stream decreased with the increasing stream order and was highest in the first order streams (Table 2). This is justified as the plot stream number versus stream length shows positive correlation (straight line) and validates Horton's Law of Stream Length indicating geometrical similarity in the sub-basin of increasing order (Figure 5). This may be due to flowing streams from high elevations, changes in the type of rock and moderate steep slopes as well as possible uplifts across the basin (Singh and Singh, 1997; Vittala et al., 2004; Chopra et al., 2005 and Rudraiah et al., 2008).

4.1.3 Mean stream length

Mean stream length (Lsm) is a characteristic feature of the drainage network component and associated basin surfaces (Strahler, 1964). It is measured by dividing it up into an overall number of segments in that order. Lsm of Hirehalla Sub-basin range from 0.51 to 5.0 Km (Table 2) and it is observed that the Lsm of any given order is higher than that of the lower order and lower than that of the next higher order. This indicates that the order's main stream is more extensive, in comparison to its past tributary streams (Das and Pardeshi, 2018).

4.1.4 Stream length ratio

Horton (1945) defined stream length ratio (Rl) as the ratio of the mean length of the given order to the next lower order of the stream segments. He suggested application of Rl as a tool for assessing the permeability of subsurface formations and that the Rl is likely to be constant at every successive order of the basin. Further, Rl value of any catchment indicates significant changes in the hydrological properties of the subsurface strata over the areas of consecutive stream orders. (Pakhmode et al., 2003). Rl values of Hirehalla Sub-basin range from 0.30 to 0.89 (Table 2). From the table 2 it is noted that, the low values of Rl indicates, that these stream flow over relatively less permeable rocks and the basin at the matured geomorphological stage.

4.1.5 Bifurcation ratio

Schumm (1956) defined a bifurcation ratio (Rb) as the ratio of the number of stream segments in a given order to the number of streams in the next higher order. It is a measure of the degree of distribution of stream network (Mesa 2006). According to Strahler (1964), geological structures donot influence the basin where Rb values are between 3 and 5. In addition, when Rb value exceeds 5 it implies that development of basin is structurally dominated. Further, low value of Rb indicates Elongated basins while high Rb values indicate circular basins (Soni, 2017). In the present investigations, the Rb value varies from 3.83 to 4.50 with an average Rb value of 3.34 (Table 2), suggests the influence of dominant geomorphic control over structural control and implying normal category of basins. Furthermore, the Rb values are similar to the universal value for maturely dissected drainage basins and the stream flows over rocks with consistent erosion resistance for the basin having Rb value of about four (Subba rao, 2008; Singh et al., 2020).

4.1.6 Length of overland flow

Length of overland flow (Lg) is one of the important factors, affecting- both the hydrological and physiographic development of water catchments (Horton, 1945; Ansari et al., 2012). Lg is the length of the stream flow-paths, which is projected to the horizontal from the point of drainage divide to a point on the adjacent stream channel, where its average is equal to half the reciprocal of average drainage density. According to Strahler (1964), the surface runoff is the result of a system of downhill flowpaths from the drainage divide to the nearest channel. A position in the river basin is crucial for these flownets, consisting of a family of orthogonal curves with respect to topographic contours that are local convergence or divergence from parallelism. The Lg value calculated for the current sub-basin is 0.39 (Table 2), which indicates a lower permeability, structural disturbance, steeper slopes and higher surface runoff (Khan et al., 2021).

Table 2: Linear aspects of Hirehalla Sub-Basin

Stream Order	Stream Number	Stream Length	Bifurcation Ratio	Mean Stream Length	Stream Length Ratio	Length of overland flow
1	300	155	4.35	0.51	0.89	
2	69	138	3.83	2.00	0.39	
3	18	54	4.50	3.00	0.30	0.39
4	04	16	4.00	4.00	0.31	
5	01	05	0	5.00	0.00	
Total	**392**	**368**	**3.34 (Avg)**			

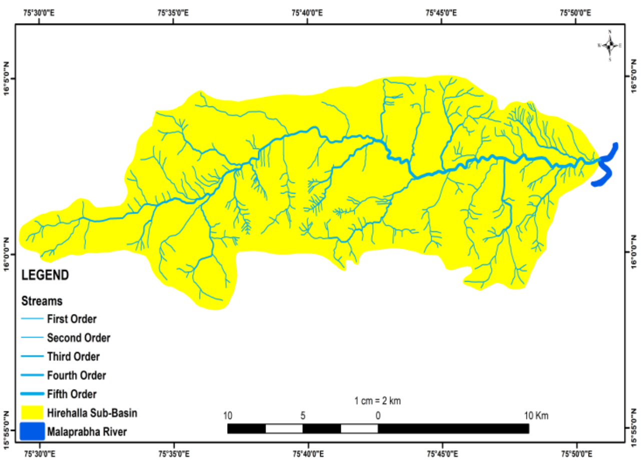

Figure 4. Drainage network map of the Hirehalla Sub-basin

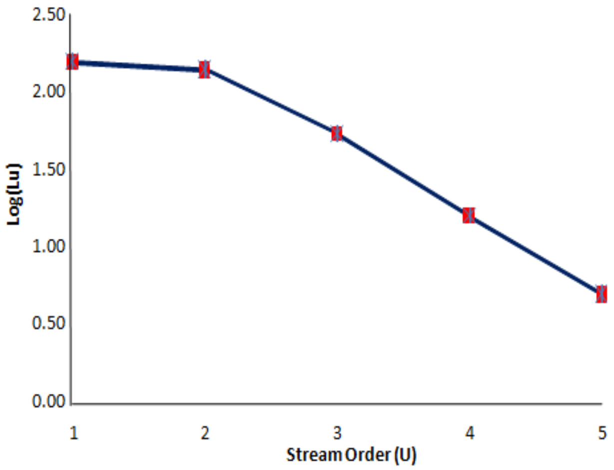

Figure 5. Regression stream length versus stream order

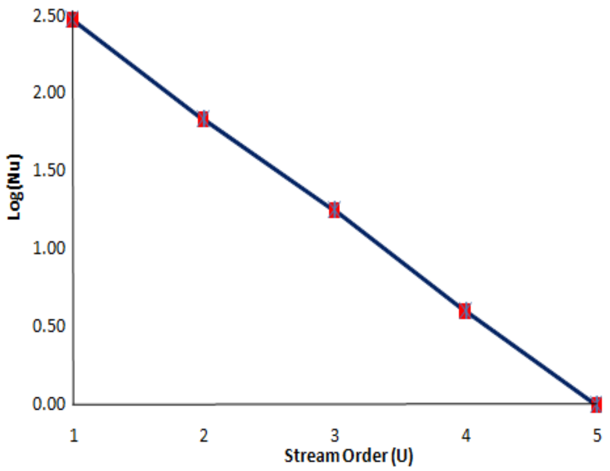

Figure 6. Regression stream number versus stream order

4.2 Aerial aspects

4.2.1 Form factor

Form factor (Ff) is the ratio of the area of the basin and the square of the basin length (Horton, 1932). Further, low value of Ff suggests elongate basin on contrary, high value of Ff suggests circular shape of basin. The computed value of Ff for the present study is 0.16 (Table 3), which indicates Hirehalla sub-basin is elongated with no rapid peak flows from the outlet. In addition, as said earlier the lower value of Ff suggests elongate basin wherein basin experiences low peak flows for longer period but basin with higher value of Ff experiences higher peak flows of smaller period.

4.2.2 Circulatory ratio

Dimensionless circulatory ratio (Rc) is defined as the ratio of basin area to the area of a circle having the same perimeter as the basin. It is observed, low values of Rc indicates elongated basin with highly permeable subsurface and high value of Rc indicates low relief and impermeable subsurface. In addition, where the basin discharge is quite large, Rc value maintained its uniformity in the range of 0.6 to 0.7 while for Rc value of one it implies that the basin is circular in shape (Miller, 1953). The Rc value for Hirehalla Sub-basin is 0.38 (Table 3), indicating that the basin does not have a circular shape. Therefore, discharge is less as compared to circular shaped basins. Additionally, young, mature and old stages of the life cycle of tributary are indicative from Rc values of low, medium and high respectively (Rai et al., 2017).

4.2.3 Elongation ratio

Elongation ratio (Re) is the ratio between the diameter of the circle of the same area as the drainage basin and the maximum basin length (Schumm, 1956). Generally, for a wide range of climate and geologic types the Re value range from 0.6 to 1.0.

Miller (1953) studied that, Re values near to 1.0 are characteristic feature of areas of low relief while where Re values range between 0.6 to 0.8, corresponds to high degree of relief and steep slope. In addition, compared to a elongated basin, the circular basin is more efficient at discharging run-off (Singh and Singh, 1997). The Re value for the present study is 0.45 (Table 3) suggesting the basin to be elongated in shape.

4.2.4 Drainage density

Horton (1932) first coined the term drainage density (Dd) to indicate channel spacing. It is an important factor which describes the climatic conditions, rock types, relief, infiltration capacity, vegetation cover, surface roughness and runoff intensity index. It is an important parameter in the determination of the time of travel by water (Langbein, 1947). Higher values of Dd suggests the area to be having impermeable subsurface, sparse vegetation, high relief and fine drainage texture where as low values of Dd shows areas of highly permeable subsurface, dense vegetation, low relief and coarse drainage texture (Nag, 1998). The main morphological factors controlling drainage density are slope and relative height. The Dd value of the present study is 1.27 Km/Km2 (Table 3), indicating permeable subsoil, coarse texture, dense vegetation cover and low relief (Soni, 2017; (Rai et al., 2017).

4.2.5 Stream frequency

Stream frequency (Fs) or channel frequency is defined as the ratio of the total number of stream segments of all orders per unit area (Horton 1932). The value of channel frequency varies for different. The high value of Fs indicates a larger number of stream availability, high rate of surface run-off and steep slope (Gundekar et al., 2011). The calculated value of Fs for the present study is 1.36 (Table 3). This increase in stream population with respect to an increasing Dd implies positive correlation between Fs and Dd (Das and Pardeshi, 2018).

4.2.6 Drainage texture

Horton (1945) defined drainage texture (Dt) as the total number of stream segments of all orders per basin. According to him, Dt includes drainage density and stream frequency and it is influenced by the infiltration capacity of the basin. Massive, resistant rock shows coarse drainage texture while subsurface underlained by soft or weak rock, show fine drainage texture. In particular, the climate and vegetation in the area determine the texture of the drainage (Dornkamp and King, 1971). Further, Smith (1950) categorized Dt into five classes based on drainage density i.e., Dd <2 (Very Coarse); between 2 and 4 (Coarse); between 4 and 6 (Moderate); between 6 and 8 (Fine) and >8 (Very Fine) drainage texture. The computed values of Dt for the present study is 1.74 (Table 3), indicating coarse drainage texture (Shrivatra et al., 2021).

4.2.7 Constant of channel maintenance

Schumm (1956) used the inverse of drainage density as constant of channel maintenance (C) and defined it as the area of basin surface needed to sustain a unit length of the stream channel. C depends on the duration of erosion and climatic history apart from geology, permeability, vegetation and relief. In the areas of close dissection the values of C is found to be very low. In generally, higher C value indicates higher permeable nature of the subsurface strata of the catchment and vice versa (Gundekar et al., 2011). The calculated value of C for the Hirehalla Sub-basin is 0.78 Km^2/Km (Table 3), that means an area of 0.78 Km^2/km is needed to support one kilometer of stream channel.

4.3 Relief aspects

4.3.1 Basin relief

Basin relief (R) is the difference in altitude between the highest and the lowest point of the basin. Hadley and Schumm (1961) state that relief controls the stream slope which in turn affects flood patterns and sediment transport capacity of the basin. Basin relief of the study area is 189 meters (Table 3; Figure 6-7).

4.3.2 Relief ratio

Schumm (1963) defined relief ratio (Rr) as the maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line. He suggested that there is a relationship between the hydrological characteristics of a watershed and the relief ratio. In addition, high values of Rr typically indicates hilly region while low values of Rr indicates pediplains and valley. The Rr value of Hirehalla sub-basin is 0.045 (Table 3). This low value of Rr implies the presence of resistant basement and low slope.

4.3.3 Ruggedness Number

Strahler (1958) stated ruggedness number (Rn) as the product of basin relief and drainage density which focuses on the structural complexity and denudational characteristics of the terrain. The higher value of Rn implies structural domination and higher proneness to erosion while low value implies lesser proneness to erosion. From the study, the Rn value was calculated to be 0.241 (Table 3), indicating that the Hirehalla Sub-Basin is resistant to erosion. This smaller Rn values in the present study suggest, a developed river basin with long drainage density, similar lithology, no structural influence and moderate slope which reduces erosional susceptibility (Pande and Das, 2016; Venkatesh and Anshumali, 2019).

Table 3 Aerial and Relief aspects of Hirehalla Sub-Basin

Parameters	Hirehalla Sub-Basin
Area	288 Km^2
Perimeter	97 km
Length	42 km
Form factor (Ff)	0.16
Circulatory ratio (Rc)	0.38
Elongation ratio (Re)	0.45
Drainage density (Dd)	1.27 Km/Km^2
Stream frequency (Fs)	1.36
Drainage texture (Dt)	1.74
Constant of Channel Maintenance (C)	0.78 Km^2/Km
Basin relief (R)	189 m
Relief ratio (Rr)	0.045
Ruggedness number (Rn)	0.024

4.3.4 Slope Analysis

Slope of a basin determines its degree of inclination with respect to the horizontal surface. An understanding of slope is vital in projects related to agriculture, planning and engineering (Sreedevi et al., 2005). In areas of different lithology and varied rate of resistance, morpho-climatic processes determine the slope of an area (Magesh et al., 2011; Gayen et al., 2013; Shrivatra et al., 2021). Slope map of the study area (Figure 8) was generated using SRTM-DEM and classified into five classes (Berhanu et al., 2013). The observation of the slope map of HSB reveals that- 0^o-5^o (Gentle), 5^o-10^o (Moderate), 10^o-15^o (Strong), 15^o-20^o (Very Strong) and 20^o-33^o (Steep) slope. Hirehalla Sub-Basin predominantly has gentle slope implying less vulnerable to run-off and erosion.

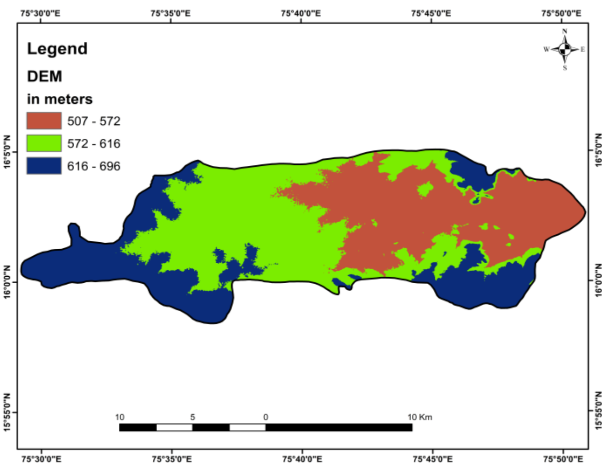

Figure 7. Digital elevation model of Hirehalla Sub-Basin

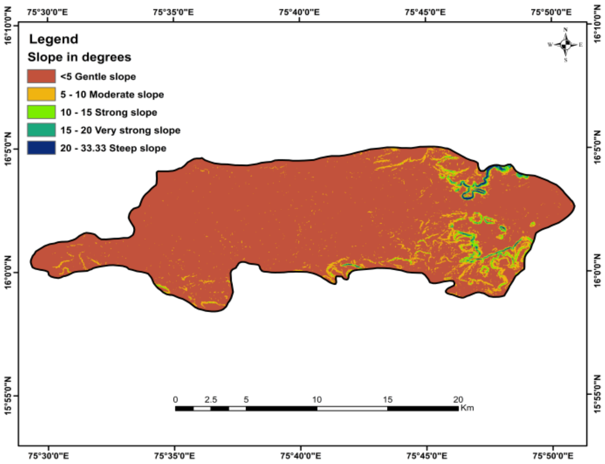

Figure 8. Slope map of Hirehalla Sub-Basin

5. Conclusion

Morphometric analysis of the Hirehalla Sub-Basin of Bagalkote District, Karnataka was carried out using topographical maps, remote sensing data and geoinformatics techniques. From the study following observations were made. Hirehalla Sub-basin geographically covers an area of 288 Km^2 with the highest stream order of five and having dendritic to sub-dendritic drainage patterns. From the values of shape parameters such as form factor (0.16), circulatory ratio (0.38) and elongation ratio (0.45) the sub-basin is asymmetrical (elongated) in shape and shows early stage of maturity. Average bifurcation value (Rb=3.34) ratio emphasis towards geomorphic development of basin. The low values and positive correlation between drainage density (1.27 Km^2/Km) and stream frequency (1.36) indicates the basin to be moderately permeable, gentle slope, low run-off and high water storage capacity. Low values of basin relief and degree of slope, suggest lesser steep, low chances of flood, resistance to erosion and capacities to transport sediments. Thus, the present study of morphometric analysis coupled with RS and GIS provides detailed information about the hydrological and geomorphological conditions of the Hirehalla Sub-basin. Further, there is good scope for future work based on above studies for proposing of location and designing of artificial recharge structures for augmenting the groundwater.

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Conflict of Interest

The authors confirm that there is no conflict of interest.

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