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Morphometric analysis of Hirerayakumpi watershed in Krishna river basin using by DEM and GIS techniques

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Abstract
The present study was taken up in the Hirerayakumpi watershed, Deodurga Taluka, Raichur district Karnataka state at 16^0 23'18" North latitude and 77^0 09' 29" East longitude. The drainage network of micro watershed was delineated and the parameters required for morphometric analysis are computed using by QGIS 2.6.1 software. The drainage pattern of the study area is dendritic with stream order 5^{th} (V) and lower streams order conquered in the selected watershed. The bifurcation ratio reflecting a geological and tectonic characteristics of the watershed was estimated at 1.45 indicate that the watershed has suffered less structural disturbance and the drainage pattern has not been distorted by structural interruption. The drainage density of watershed is 2.54 km/km^2 which indicates the closeness of spacing of channels, thus providing a quantitative measure of the average length of stream channel for the whole watershed. The values of form factor and circulatory ratio of watershed indicate that the watershed is approaching towards the fern shape. The values of length of overland flow of the watershed indicate that the areas are associated with high runoff and less infiltration. The low value of ruggedness number indicates that watershed is having gentle slope. The research of morphometric analysis study helps to plan the selection and adoption of the soil and water conservation measures and the crop management practices in the prospect.

Keywords: Areal, geo-morphologic, micro watershed, morphometric, relief

Introduction
Morphometry deals with mathematical measurement of morphometric parameters of drainage basin. In geomorphology, quantitative description and analysis of landforms are practiced (Sukristiyanti *et al.* 2018) [23]. Geographical Information System (GIS) has emerged as an efficient tool in delineation of watershed and drainage pattern and its planning. GIS and remote sensing techniques can be employed for the identification of morphological features and analyzing properties of basin (Waikar and Nilawar, 2014) [25]. Therefore, the morphometric techniques are taken to describe and classify the various parameters of Krishna Sub basin. The quantitative analysis of the drainage basin and its characteristics has become an essential objective of the present study. The close relationship between hydrology and geomorphology play an important role in the drainage morphometric analysis (Horton, 1932) [7]. Morphometric feature of a watershed typically covers the quantitative aspects and physical characteristics of the watershed. It is static criteria or natural characteristics that do not change easily over time. It also required to prioritize sub-watersheds for effective natural resources management (Javed *et al.* 2009; Sharma *et al.* 2010; Ajay *et al.* 2014; Ayele *et al.* 2017) [9, 18, 2, 3].

The drainage pattern is a network of stream channels of all orders having a particular fluvial system within the basin area indicative of the homogeneous character of geology, climate, tectonic history, drainage lines and human interference. In a particular basin sprawl, a drainage type is developed when a drainage network of channel lines have adjusted together with the subsurface structure (Ajay *et al.* 2014) [2]. A drainage basin is a part of land where water from rainfall is contributing to a common point. It is useful element of the catchment, and all flow of water is governed by its properties (Christopher *et al.* 2010) [4]. GIS and remote sensing techniques are efficient tools used to analyze the hydrological process of the drainage basin (Waikar and Nilawar, 2014) [25]. Drainage basin analysis is an essential used to assess and manage both ground and surface water resource. Important characteristics of the drainage basin such as shape, length of tributaries, size and slope are highly correlated with drainage basin hydrological process (Rastogi and Sharma, 1976) [16].

Morphometry refers to the measurement and evaluation of the configuration of the earth's surface, including the shape and dimensions of its landforms, and different aspects of drainage basins (Clark, 1965) [5]. Morphometric analysis is performed through the measurement and calculation of basic parameters, derived parameters and shape parameters of drainage basins using DEM's, GIS tool and mathematical equations developed for this purpose (Mesa, 2006; Thomas *et al.* 2012; Sujatha *et al.* 2013; Yanina. *et al.* 2014) [13, 24, 22, 26]. The measured bifurcation ratio (Rb) for example refers to the degree in which geological structure controls the drainage network, whereas, a high value of mean bifurcation ration (Rbm) of a drainage system indicates the runoff and other external agents that contribute to the formation of drainage networks (Kaliraj *et al.* 2015) [10].

The values of several morphometric parameters of the watershed aims to know and correlate the linear aspects are Watershed length (L), Watershed perimeter (P), Number and order of streams, Stream length (L_u), Mean stream length (L_{sm}), Stream length ratio (R_L) and Bifurcation ratio (R_b). The areal aspects are Drainage density (D_d), Constant of channel maintenance (C), Stream frequency (F_s), Drainage texture (R_t), Form factor (R_f), Circulatory ratio (R_c), Elongation ratio (R_e), Length of overland flow (L_g), Compactness co-efficient (C_c), Shape index/factor (S_b) and Texture ratio (T_r). The relief aspects of drainage network are Relative relief (R_R) and Relief ratio (R_r), Ruggedness number (R_N), Geometric number (G_N) and Time of concentration (T_c).

The main objective of the study is to delineate the geo-morphological characteristics of watershed include morphometric analysis and prioritization of watershed is carried out for Hirerayakumpi watershed of Krishna river basin of Raichur district Karnataka state, India using Geographical Information System (GIS) techniques. This study bridges to develop and apply integrated method for combining the information obtained by analysing multi-source remotely sensed data in a GIS environment to produce effective information as a part of watershed management and understanding the drainage basin hydrology is a vital to prior and design proper type of soil and water conservation work.

Materials and Methods

Description of the study area and location

The current study area is located in the Hirerayanakumpi village and its surroundings, Deodurga Taluka, Raichur district Karnataka state, India. The total area of watershed which is undertaken for the study is 35.17 km^2. The watershed lies between 16^0 23' 07'' N to 16^0 26' 21'' N latitude and 77^0 04' 59'' E to 77^0 09' 33'' E longitude. The physiography on the whole watershed is gently sloping and the total relief is 82 m. The average annual rainfall of watershed is 615 mm and minimum and maximum temperatures recorded were 15.4^{o}C and 43.15 ^{o}C, respectively. While the monthly reference evapotranspiration (ET_o) was in the range of 120.0 to 238.2 mm. Relative humidity of over 78 per cent is common during monsoon period. Wind speeds exceeding 6-15 km/h are common during the months of June and July.

Data used

Table 1: Details of the various data sets used for developing the watershed maps

Sl. No.	Type of data	Details of data	Source of data
1.	Survey of India (SoI) topo sheets	56H/3 (E43 X 3) on scale 1:50000	Survey of India (SoI), Bengaluru
2.	Aster GDEM data	3 arc-seconds (90 m) grid wise reduced levels (elevation) values	United States Geological Survey (USGS) (http://srtm.esi.egiar.org/selection/inputcoord.asp and http://seamless.usgs.gov/)

The Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) 30 m resolution was used to digitize study watershed and generate drainage pattern. The data was downloaded from United States Geological Survey (USGS) website. First SoI toposheets are geo-coded with the help of known ground control points (GCPs) on it. These geo-coded toposheets are then mosaic to create the boundary map of study area with relevant details, in the form of shape file using QGIS 2.6.1 software. QGIS (Quantum Geographic Information System) is a free, open-source software that allows users to create, edit, visualize, analyze, and publish geospatial information. The clipping operation is carried out for obtaining required details for study area from the mosaic toposheets. The DEM data of extract Area of interest to UTM zone 43 N coordinate system using QGIS 2.6.1 under data management tools of project raster.

The flow direction and accumulation map of the watershed was created using flow direction and accumulation tools of the same spatial analyst tools of hydrology option. After delineation of the watershed slope map, contour map aspect map, drainage density and drainage pattern maps were generated using SRTM digital elevation model (DEM) in the QGIS software.

The arrangement of the stream system of a drainage basin has been expressed quantitatively with stream order, drainage density, bifurcation ration and stream length ratio (Horton 1945) [8]. Horton's law of stream lengths projected the geometric association existing between the statistics of stream segments in consecutive stream orders. The law of basin areas shows the mean basin area of successive ordered streams forming a linear relationship. To evaluate the drainage basin morphometry, various parameters like stream number, stream order, stream length, stream length ratio, bifurcation ratio, basin length, basin area, relief ratio, elongation ratio, drainage density, stream frequency, form factor and circulatory ratio, etc., have been analysed using the standard mathematical formulae given in Table 2.

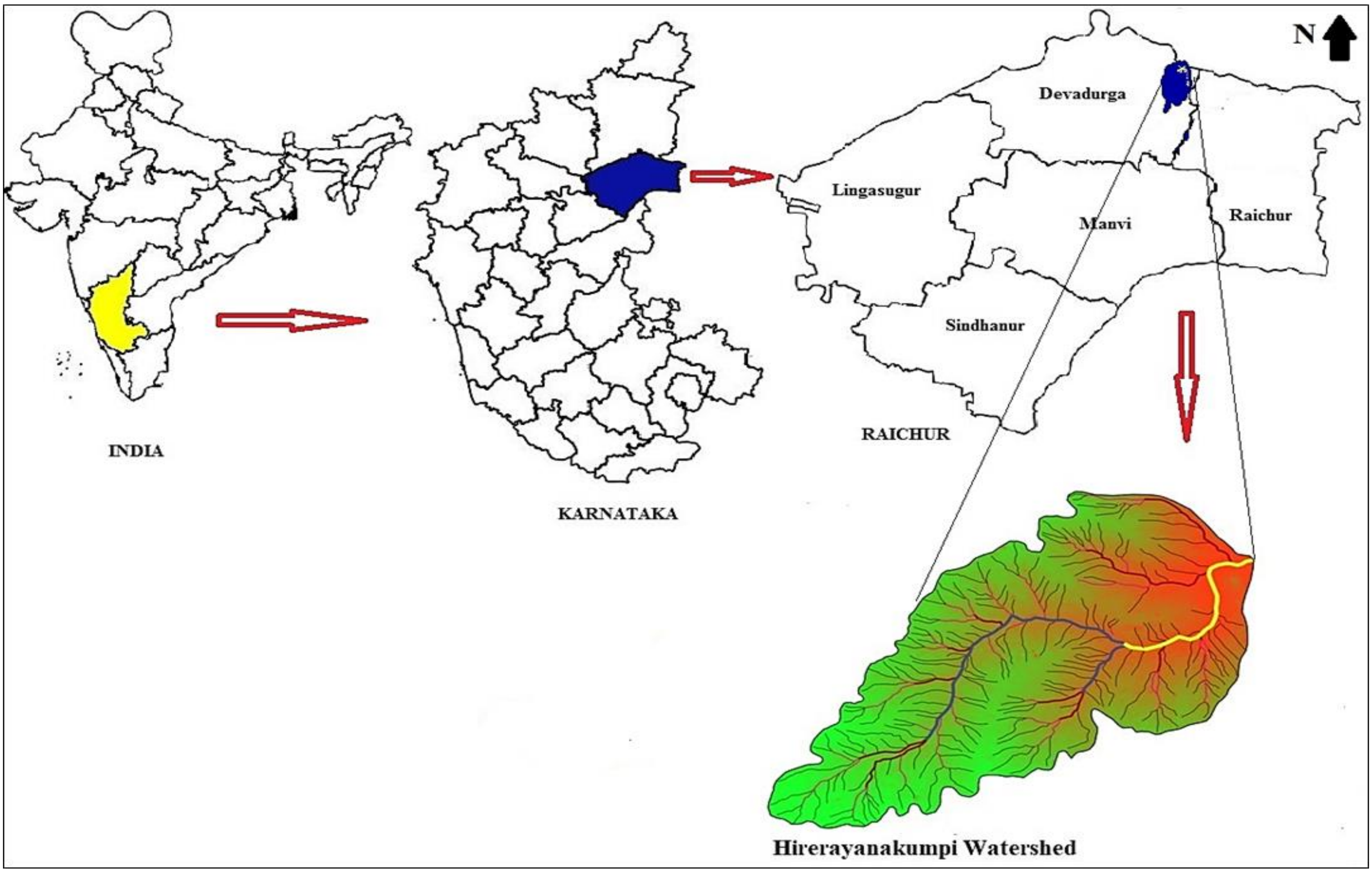

Fig 1: The location map of the watershed study area

Table 2: Linear aspects of watershed

Sl. No.	Parameter	Formula	Reference
1.	Watershed length (L)	$L=1.31 \times 2A^{0.568}$ Where, L= Watershed length (km), A= Area of the watershed (km^2)	Nookaratnam *et al.*, (2005) [15]
2.	Stream order (u)	Hierarchical rank	Strahler (1964) [21]
3.	Stream length (L_u)	Length of the stream (km)	Horton (1932) [7]
4.	Mean stream length (L_{sm})	$L_{sm} = L_u/N_u$ Where, L_{sm} = Mean stream length, L_u = Total stream length of order 'u', N_u = Total no. of stream segments of order'u'	Strahler (1964) [21]
5.	Stream length ratio (R_L)	$R_L = L_u/L_{u-1}$ Where, R_L = Stream Length Ratio L_u = The total stream length of the order 'u' L_{u-1} = The total stream length of its next lower order	Horton (1945) [8]
6.	Bifurcation ratio (R_b)	$R_b = N_u/N_{u+1}$ Where, R_b = Bifurcation ratio N_u = Total no. of stream segments of order'u' N_{u+1} = Number of segments of the next higher order	Schumm (1956) [17]
7.	Mean bifurcation ratio (R_{bm})	R_{bm} = Average of bifurcation ratios of all orders	Strahler (1957) [20]

Table 3: Relief aspects of watershed

Sl. No.	Parameter	Formula	Reference
1.	Relative relief (R_R)	$R_R = H/L_p$ Where, R_R = Relative relief, H = Watershed relief (km) L_p = Length of perimeter (km)	Melton (1957) [12]
2.	Relief ratio (R_r)	$R_r = H/L$ Where, R_r = Relief ratio, H = Watershed relief (km) L = Watershed length (km)	Schumm (1956) [17]

3.	Ruggedness number (R_N)	$R_N = H \times D_d$ Where, R_N = Ruggedness number, H = Watershed relief (km) D_d = Drainage density (km/km^2)	Horton (1945) [8]
4.	Geometric number (G_N)	$G_N = H \times D_d / S_g$ Where, S_g = Slope of ground surface (km/km^2) H = Watershed relief (km), D_d = Drainage density (km/km^2)	Horton (1932) [7]
5.	Time of concentration (T_c)	$T_c = 0.0195 L^{0.77} S^{-0.385}$ Where, T_c = Time of concentration (min) L = Length of stream reach (m) S = Average slope of the stream reach (%)	Horton (1945) [8]

Table 4: Areal aspects of watershed

Sl. No.	Parameter	Formula	Reference
1.	Drainage density (D_d)	$D_d = L_u/A$ Where, D_d = Drainage density (km/km^2) Lu = Total stream length of all orders A = Area of the basin (km^2)	Horton (1945) [8]
2.	Constant of channel maintenance (C)	$C = 1/D_d$ Where, C= Constant of channel maintenance D_d = Drainage density (km/m^2)	Schumm (1956) [17]
3.	Stream frequency (F_s)	$F_s = N_u/A$ Where, F_s = Stream frequency N_u = Total no. of streams of all orders A = Area of the basin (km^2)	Horton (1932) [7]
4.	Drainage texture (R_t)	$R_t = N_u/P$ Where, R_t = Drainage texture N_u = Total no. of streams of all orders P = Perimeter (km)	Horton (1932) [7]
5.	Form factor (R_f)	$R_f = A/L^2$ Where, R_f = Form factor A = Area of the watershed (km^2) L^2 = Square of watershed length	Horton (1945) [8]
6.	Circularity ratio (R_c)	$R_c = 4\pi \times A/P^2$ Where, R_c = Circularity ratio π = 'Pi' value i.e., 3.142 A = Area of the basin (km^2) P^2 = Square of the perimeter (km)	Miller (1953) [14]
7.	Elongation ratio (R_e)	$Re = 1.128 \sqrt{(A/L)}$ Where, R_e = Elongation ratio A = Area of the watershed (km^2) L = Watershed length (km)	Schumm (1956) [17]
8.	Length of overland flow (L_g)	$L_g = 1/2 \times D_d$ Where, L_g = Length of overland flow D_d = Drainage density (km/km^2)	Horton (1932) [7]
9.	Compactness co-efficient (C_c)	$C_c = 0.2821 \times P/A^{0.5}$ Where, P = Perimeter (km) A = Area of watershed (km^2)	Gravelius (1914) [6]
10.	Shape factor (S_b)	$S_b = L^2/A$ Where, S_b = Shape factor A = Area of watershed (km^2) L = Watershed length (km)	Horton (1945) [8]
11.	Texture ratio (T_r)	$T_r = N_1/P$ Where, N_1 = Total No. of first order streams P = Perimeter (km)	Horton (1945) [8]

Results and Discussion

Stream order

Stream order is the index of size and scale of the drainage basin. An estimation of the stream flow can be deduced from stream order. The classification of the highest trunk steam order is up to 5^{th} order in the watershed.

Stream number

The total number (252) of streams of the Hirerayakumpi watershed in the respective stream order categories are presented in Table 5. More number of first order stream observed in the hilly regions of the study area indicates complex terrain and less permeable bedrock lithology. Large number of streams indicate that the topography is rugged and the streams are intensively eroding their channels. Less number of streams in irrespective of its drainage area indicates a mature topography of its stream.

Stream length

The first order stream total length is total 115.52 km, second order has a total length of 22.88 km, third order has a total length of 11.89 km, fourth order covers a total length of 6.88 km, fifth order covers a total length of 3.86 km and the total length of all streams covering all these orders is 161.03 km (Table 5). Hence, it is observed that the first order stream has the highest total stream length and the number of streams because they are distributed more effectively than the other orders. The observation of stream order verifies the Horton's law of stream number *i.e.* the number of stream segment of each order forms an inverse geometric sequence with order number (Adarsha *et al.* 2022) [1].

Mean stream length and Stream length ratio

The mean stream length of the watershed is 0.59 km for first order and 3.86 km for fifth order (Table 5). The mean stream length of stream increases with increase of the order.

The stream length ratio has an important relationship with the surface flow discharge and erosional stage of the basin and the calculated values were presented in the Table 5. An increasing trend in the stream length ratio from lower order to higher order indicates their mature geomorphic stage.

Bifurcation ratio

Horton (1945) [8] considered bifurcation ratio as an index of relief and dissection while Strahler (1957) [20] opined that bifurcation ratio shows only a small variation for different regions with different environments except where powerful geological control dominates. According to Schumm (1956) [17], the term bifurcation ratio may be defined as the ratio of the number of the stream segments of given order to the number of segments of the next higher orders. It is a dimensionless property and shows the degree of integration prevailing between streams of various orders in a drainage basin. The bifurcation ratio for the Hirerayakumpi watershed varies from 2.0 to 5.5 (Table 5).

According to Strahler (1964) [21], the values of bifurcation ratio characteristically range between 3.0 and 5.0 for drainage basin in which the geological structures do not disturb the drainage pattern. The mean bifurcation ratio characteristically was found 4.01 which indicate low rainfall, shallow weathering and medium slopping terrain. The high bifurcation ratio of the Hirerayakumpi watershed stream clearly indicates the factor of geological control on the drainage pattern.

Drainage density and Stream frequency

The drainage density of the Hirerayakumpi watershed reveals that density value is 4.58 km/km^2 (Fig.2 and Table 5). The low drainage density is privileged in the region of highly permeable subsoil materials, under dense vegetation cover and where relief is squat (Adarsha *et al.* 2022) [1]. Stream frequency is 7.11 which high stream frequency observed in the study area reflecting, the steep ground slope and greater rock-permeability in those basins. It also shows the runoff is low and the infiltration is high. A high proportion of first-order streams indicates the structural weakness present in the watershed dominantly in the form of fractures/lineaments.

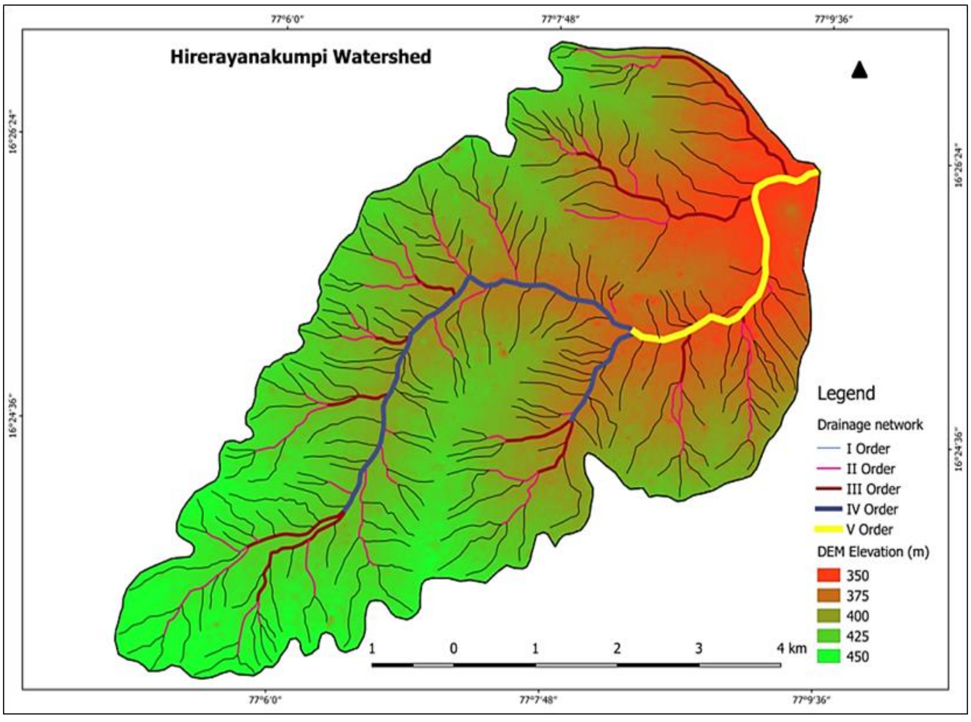

Fig 2: Drainage network map

Table 5: Morphometric characteristics results of the Hirerayakumpi watershed

Sl. No.	Morphometric characteristic	Results			
1.	Stream order, Number, Stream length in km and Mean stream length in km	**Stream order**	**No**	**Stream length in km**	**Mean stream length in km**
		I	196	115.52	0.59
		II	40	22.88	0.57
		III	11	11.89	1.08
		IV	2	6.88	3.44
		V	1	3.86	3.86
2.	Stream length ratio and Bifurcation ratio	**Stream length ratio**		**Bifurcation ratio**	
		II/I	0.200	I/II	4.90
		III/II	0.520	II/III	3.64
		IV/III	0.579	III/IV	5.5
		V/IV	0.561	IV/V	2.0
3.	Area Sq.km	35.17			
4.	Perimeter (P) (km)	30.27			
5.	Basin Length(km)	19.79			
6.	Elevation	350m (Outlet), 432(Hill)			
7.	Elongation ratio	1.10			
8.	Form factor	0.09			
9.	Circularity ratio	0.48			
10.	Compactness coefficient	1.44			
11.	Shape factor	11.14			
12.	Drainage density	4.58			
13.	Stream frequency	7.11			
14.	Texture ratio	6.48			
15.	Constant channel maintenance	0.22			
16.	Relief ratio	0.0041			
17.	Relative relief	0.0027			
18.	Basin Relief	0.0820			
19.	Ruggedness No.	0.38			
20.	Time of concentration	118.00 min			

Texture ratio and Form factor

The texture ratio of the Hirerayakumpi watershed is 6.48, which indicated high coarse texture (Smith, 1950). The value of the form factor should not be more than 0.8 (Waikar and Nilawar, 2014) [25]. The form factor ratio value for this study area is 0.09, which has a medium range value of form factor. Therefore, the basin is slightly elongated in shape with low peak flow and longer duration of flow (Table 5).

Circulatory ratio and Elongation ratio

The circulatory ratio values of the watershed was found less than 0.5 i.e. 0.48 indicating the characteristics of an slightly elongated basin and susceptibility to food hazards at the outlet of the basin (Miller 1953) [14].

The elongation ratio value of the study area is 1.10 (Table 5). The value is close to 1.0, which implies that it is typical of regions of very low relief and indicates that there are fewer geomorphological controls on stream networks.

Basin relief and Relief ratio

In the study, basin relief is obtained as 82 m with the maximum height of the whole basin is 432 m and the lowest is 350 m. The contour map (Fig. 3) shows contour lines of study area with 10 m contour interval, it is used to study topographic features of drainage basin.

The value of the relief ratio indicate steep slope and high relief and vice-versa and is an indicator of the intensity of erosion process operating on slope of the basin (Schumm 1956) [17]. The value of relief ratio in micro-watershed is 0.0041 indicating moderate relief and moderate slope (Table 5).

Ruggedness number and Time of concentration

The ruggedness value of the Hirerayakumpi watershed is 0.38 (Table 5), which shows the terrain of the watershed is moderately rugged. If the watershed is more rugged, high sediment transport will take place, thereby exposing it to soil erosion (Kumar and Joshi, 2015) [11].

The time of concentration was found 118 minutes which reveals that the time required for an entire watershed to contribute to runoff from the remote point to the outlet of the watershed (Table 5).

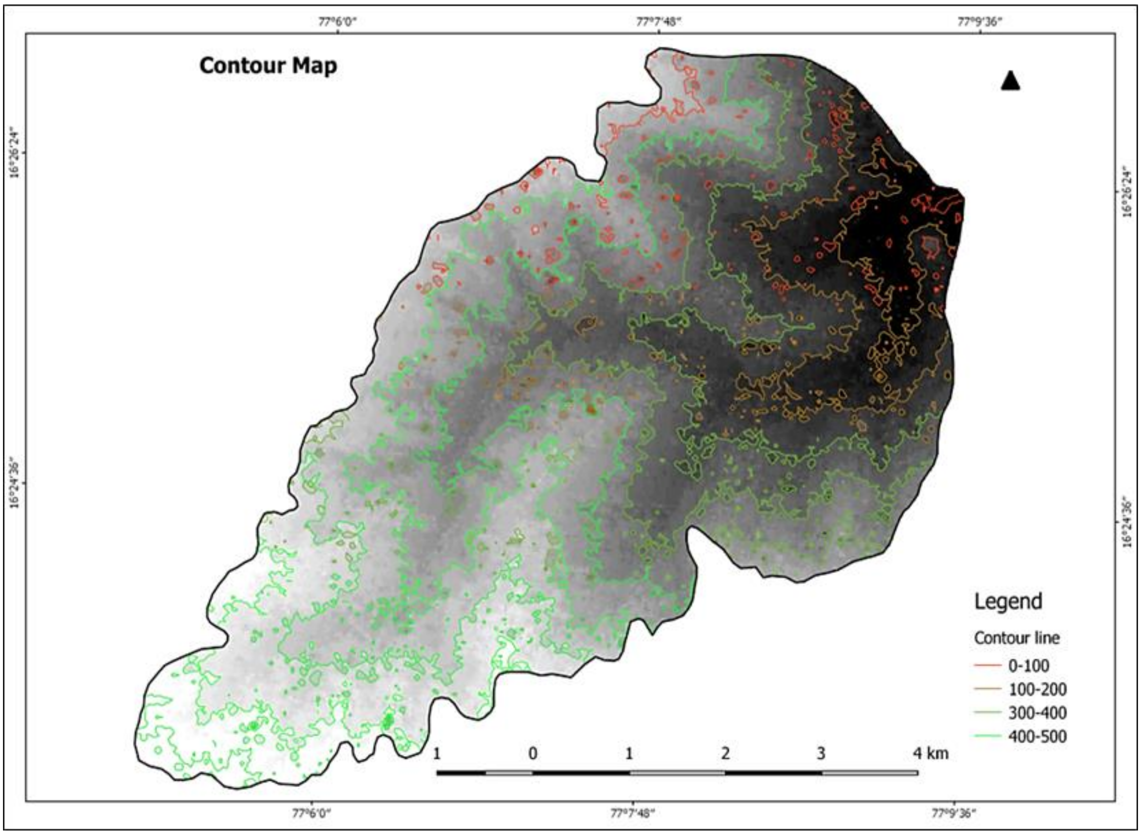

Fig 3: Contour map

Slope of the watershed

The detailed procedure of generating slope map from the ASTER GDEM data is explained in the material and methods chapter. The DEM and contour map of the study area is shown in Fig. 4. The major part of the area is having gently slope (Less moderate).

However, variations in the slope is that 0 to 9 per cent. On south-eastern and north-western sides, small residual hills are appearing and where the slope is more than 5 per cent.

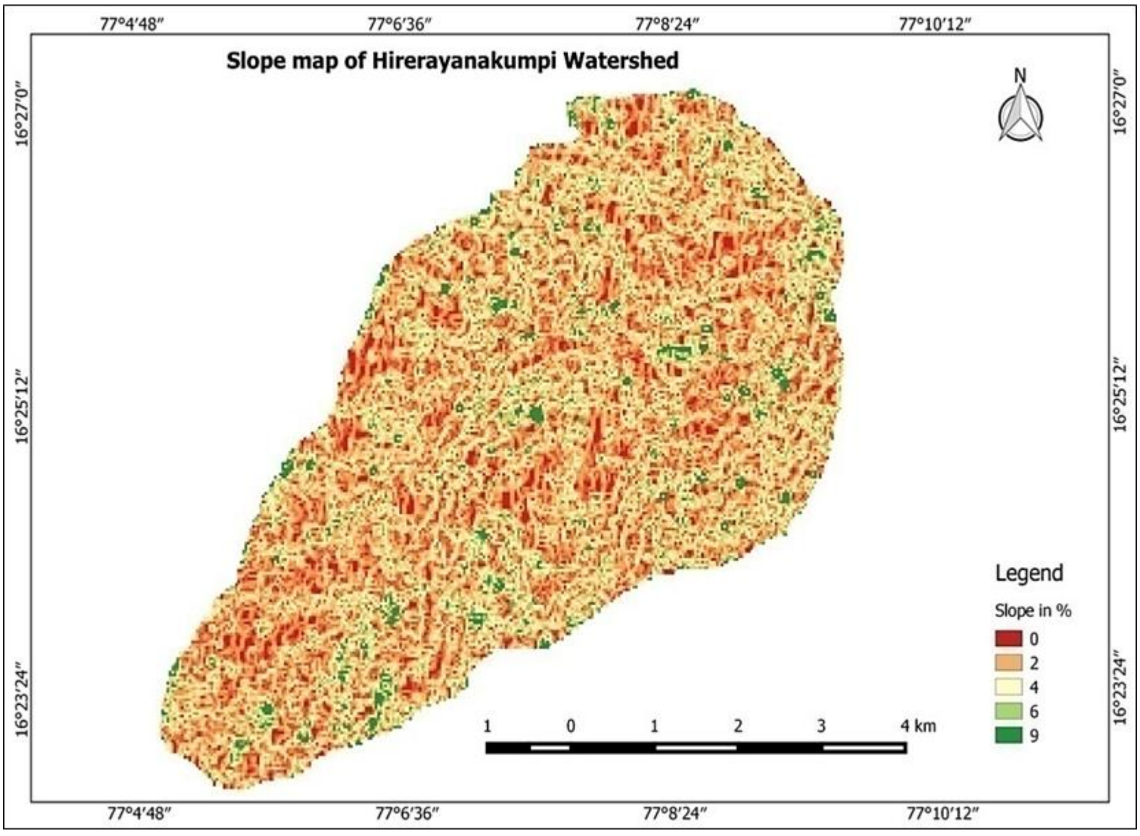

Fig 4: Slope map

Conclusions

The morphometric analysis of different sub-watersheds shows their relative characteristics with respect to hydrologic response of the catchment. The morphometric analysis of nine sub-watersheds exhibits the dendritic drainage pattern and the variation in stream ratio might be due to changes in slope as well as topographic features of the study region.

However, more circular watersheds have a greater risk of flash floods as there will be a greater possibility that the entire area may contribute runoff at the same time and may result in high risk of erosion and sediment load.

The morphometric analysis is carried by the measurement of linear, aerial and relief aspects of basins. Detailed morphometric study of all sub-watersheds shows dendritic to sub-dendritic drainage patterns, which thus indicate homogenous lithology and variations of values of bifurcation ratio among the sub-watersheds attributed to difference in topography and geometric development. The maximum stream order frequency is observed in case of first-order streams and then for second order. Hence, it is noticed that there is a decrease in stream frequency as the stream order increases and vice versa. The values of stream frequency indicate that watershed show positive correlation with increasing stream population with respect to increasing drainage density.

The high relief values indicated the presence of long and steep slopes which implied lower time of concentration of overland flow and possibilities of flash floods and high susceptibility to soil erosion. A database of initial assessment for strategic planning, management and decision making that include watershed prioritization for soil and water conservation. Assessment of surface and groundwater potential, soil erosion studies, flash flood hazard assessment, etc. The present study is valuable for erosion control, watershed management, land and water resources planning and future prospective related to runoff study.

References

1. Adarsha Murukannappa, Ashoka HG. Morphometric analysis of Chilenahalli micro-watershed in the North-eastern dry zone of Karnataka using GIS and remote sensing techniques. International Journal of Environmental and Climate Change. 2022;12(11):100-113.
2. Ajay P, Mahmood K, Vijay S, Paru P Th, Joy J, Nayan P, *et al*. Morphometric and land use analysis for watershed prioritization in Gujarat State, India. International Journal of Science Engineering and Research. 2014;5(2):1-7.
3. Ayele AF, Hiroshi Y, Katsuyuki SH, Nigussie H, Kifle W. Quantitative analysis and implications of drainage morphometry of the Agula watershed in the semi-arid northern Ethiopia. Applied Water Science. 2017;7:3825-3840.
4. Christopher O, Idowu AO, Olugbenga AS. Hydrological analysis of Onitsha north east drainage basin using geoinformatic techniques. World Applied Science Journal. 2010;11(10):1297-1302.
5. Clark J. Morphometry from Maps. In: Dury GH, Ed., Essays in Geomorphology. Heinemann, London; c1965. p. 235-274.
6. Gravelius H. Flusskunde, Goschensche Verlagshandlung, Berlin; c1914. p. 176.
7. Horton RE. Drainage-basin characteristics. Transactions, American Geophysical Union. 1932;13(1):350-361.
8. Horton RE. Erosional development of streams and their drainage basins: hydro physical approach to quantitative morphology. Geology Society of American Bulletin. 1945;56:275-370.
9. Javed A, Khanday MY, Ahmed R. Prioritization of sub watersheds based on morphometric and land use analysis using remote sensing and GIS techniques. Journal of Indian Society of Remote Sensing. 2009;37:261-274.
10. Kaliraj N, Chandrasekar N, Magesh S. Morphometric analysis of the river Thamirabarani sub-basin in Kanya Kumari district, South West Coast of Tamil Nadu, India, using remote sensing and GIS. Environmental Earth Sciences. 2015;73:7375-7401.
11. Kumar P, Joshi V. Characterization of hydro geological behavior of the upper watershed of River Subarnarekha through morphometric analysis using remote sensing and GIS approach. International Journal of Environmental Sciences. 2015;6(4):429-447.
12. Melton M. An analysis of the relations among elements of climate, surface properties and geomorphology. Department of Geology, Columbia University, Technical Report, 11, Project NR 389-042. Office of Navy Research, New York; c1957.
13. Mesa LM. Morphometric Analysis of a Subtropical Andean Basin (Tucuma'n, Argentina). Environmental Geology. 2006;50:1235-1242.
14. Miller VC. A quantitative geomorphic study of drainage basin characteristics in the Clinch Mountain area, Virginia and Tennessee; c1953. p. 389-402.
15. Nookaratnam K, Srivastava YK, Rao VV, Amminedu E, Murthy KSR. Check dam positioning by prioritization of micro-watersheds using SYI model and morphometric analysis-remote sensing and GIS perspective. Journal of the Indian Society of Remote Sensing. 2005;33(1):25-38.
16. Rastogi R, Sharma T. Quantitative analysis of drainage basin characteristics. Journal of Soil and Water Conservation. 1976;26(1-4):18-25.
17. Schumm SA. Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. Geological Society of America Bulletin. 1956;67(5):597-646.
18. Sharma SK, Rajput GS, Tignath S, Pandey RP. Morphometric analysis and prioritization of a watershed using GIS. Journal of Indian Water Research Society. 2010;30(2):33-39.
19. Smith KG. Standards for grading texture of erosional topography. American Journal of Science. 1950;248(9):655-668.
20. Strahler AN. Quantitative analysis of watershed geomorphology. Transactions, American Geophysical Union. 1957;38:913-920.
21. Strahler AN. Quantitative geomorphology of drainage basins and channel networks. In: Ven Te Chow (Ed.) Hand Book of Applied Hydrology. McGraw Hill Book Company, New York; c1964. p. 439-476.
22. Sujatha E, Selvakumar R, Rojasimman U, Victor R. Morphometric Analysis of Sub-Watersheds in Parts of Western Ghats, South India using ASTER DEM. Geomatics, Natural Hazards and Risk. 2013;6:326-341.
23. Sukristiyanti S, Maria R, Lestiana H. Watershed-based morphometric analysis: A review. IOP Conference Series: Earth and Environmental Science. 2018;118(1):120-28.

24. Thomas J, Joseph S, Thrivikramji K, Abe G, Kannan N. Morphometric Analysis of Two Tropical River Basins of Contrasting Environmental Settings, the Southern Western Ghats, India. Environmental Earth Sciences. 2012;66:2353-2366.
25. Waikar ML, Nilawar AP. Morphometric analysis of a drainage basin using geographical information system: A case study. International Journal of Multidiscipline Current Research. 2014;2(2):179-184.
26. Yanina M, Esper A, Perucca LP. Geomorphology and Morphometry of the de La Flecha River Basin, San Juan, Argentina. Environmental Earth Sciences. 2014;72:3227-32337.