International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-09, Issue-01, Apr 2023

Morphometric Analysis of Drainage Basin through GIS & RS: A Case Study of Govardhanagirivagu, Wanaparthy, Telangana, India.

A.Mallikarjun[1*], V.Janaki[1], I. Panduranga reddy[1]

[1] Department of Geology, University College of Science, Osmania University, Hyderabad.

mallikarjuny89@gmail.com

ABSTRACT - Land and water resources are generally depleting due to rapid increase in population, urbanization and industrialization. The demand has increased tremendously for these resources; hence optimal utilization of essential for sustainable development. The study indicates that analysis of morphometric parameters with the help of geographic information system (GIS) would prove a viable method of characterizing the hydrological response behavior of the watershed. It is also well observed that remote sensing satellite data is emerging as the most effective, time saving and accurate technique for morphometric analysis of a basin. This technique is found relevant for the extraction of river basin and its stream networks through ASTER (DEM) in conjunction with remote sensing satellite data. The present study deals mainly with the geometry, more emphasis being placed on the evaluation of morphometric parameters such as stream order, stream length, bifurcation ratio, drainage density, stream frequency, texture ratio, elongation ratio, circular ratio and factor ratio etc., are calculated. The drainage area of the basin is 122.77km^2 and shows sub-dendritic to dendritic drainage pattern. The study area is designated as fifth order basin with the drainage density 1.63km/km^2.The current study focuses mostly on geometry, but it also considers morphometric factors like stream order (Nu), which reveals that the drainage basin has a dendritic pattern with a basin bifurcation ratio 4.92 to 3.00. The analysis of these sub-watersheds revealed that first-order streams have a larger overall count and length, but their length decreases when stream order is raised. The increase in stream length ratio from lower to higher order shows that the study area has reached a mature geomorphic stage.

Keywords: Morphometric analysis, Goverdhanagirivagu basin, Drainage Density, GIS, RS

I. INTRODUCTION

Remote sensing and GIS methods, which have been proven to be efficient, are used for drainage basin delineation, updating, and morphometric analysis. The drainage basin analysis must be taken into account in every hydrological investigation, including the assessment of groundwater potential and groundwater management. Numerous important hydrologic phenomena can be correlated using the physiographic characteristics of drainage basins, including size, form, slope of the drainage area, drainage density, size and length of the tributaries, etc. Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Clarke 1996; Agarwal 1998; Obi Reddy et al.2002). The morphometric analysis is done successfully through measurement of linear, aerial, relief, gradient of channel network and contributing ground slope of the basin (Nautiyal 1994; Nag and Chakraborty, 2003; Magesh et al. 2012b).

A widely acknowledged principle of morphometry is that drainage basin morphology reflects various geological and geomorphological processes over time, as indicated by various morphometric studies (Horton 1945; Strahler 1952, 1964; Muller 1968; Shreve 1969; Evans 1972, 1984; Chorley et al. 1984; Merritt's and Vincent 1989; Ohmori 1993; Cox 1994; Oguchi 1997; Burrough and McDonnell 1998; Hurtrez et al. 1999). It is well established that the influence of drainage morphometry is very significant in understanding the landform processes, soil physical properties and erosional characteristics.

Besides, the quantitative analysis of drainage system is an important aspect of characteristic of watershed (Strahler 1964). It is important in any hydrological investigation like assessment of groundwater potential, groundwater management, basin management and environmental

 DOI : 10.35291/2454-9150.2023.0085

assessment. Drainage characteristics of many river basins and sub-basins in different parts of the globe have been studied using conventional methods (Horton 1945; Strahler 1957, 1964; Krishnamurthy et al. 1996).

The digital elevation model (DEM) of the area was generated to deduce the morphometric parameters like drainage basin area, drainage density, drainage order, relief and network diameter in GIS environment. Combination of the remote sensing satellite data and hydrological and spatial analysis in GIS environment is made easy to identify and discriminate the drainage area (Pirasteh et al. 2010). The geographic and geomorphic characteristics of a drainage basin are important for hydrological investigations involving the assessment of groundwater potential, etc.

The present study aims at using the remote sensing and GIS technology to compute various parameters of morphometric characteristics of the Goverdhanagirivagu watershed. This is in consonance with the latest developments and researches as cited above.

II. STUDY AREA

The present study area is located in the Wanaparthy district of Telangana. The total geographical area of the basin is $122.77km^2$.Goverdhanagirivagu covers the parts of Weepangandla, Chinnambavi and Pebbair mandals. The Goverdhanagirivagu geographically located lies between $16^{0}02'30''$N to $16^{0}11'30''$N latitudes and $78^{0}01'30''$E to $78^{0}09'30''$E longitudes falling in Survey of India Toposheet No.56 L/4 (E44S4) on a scale of 1:50,000 (Fig:1).

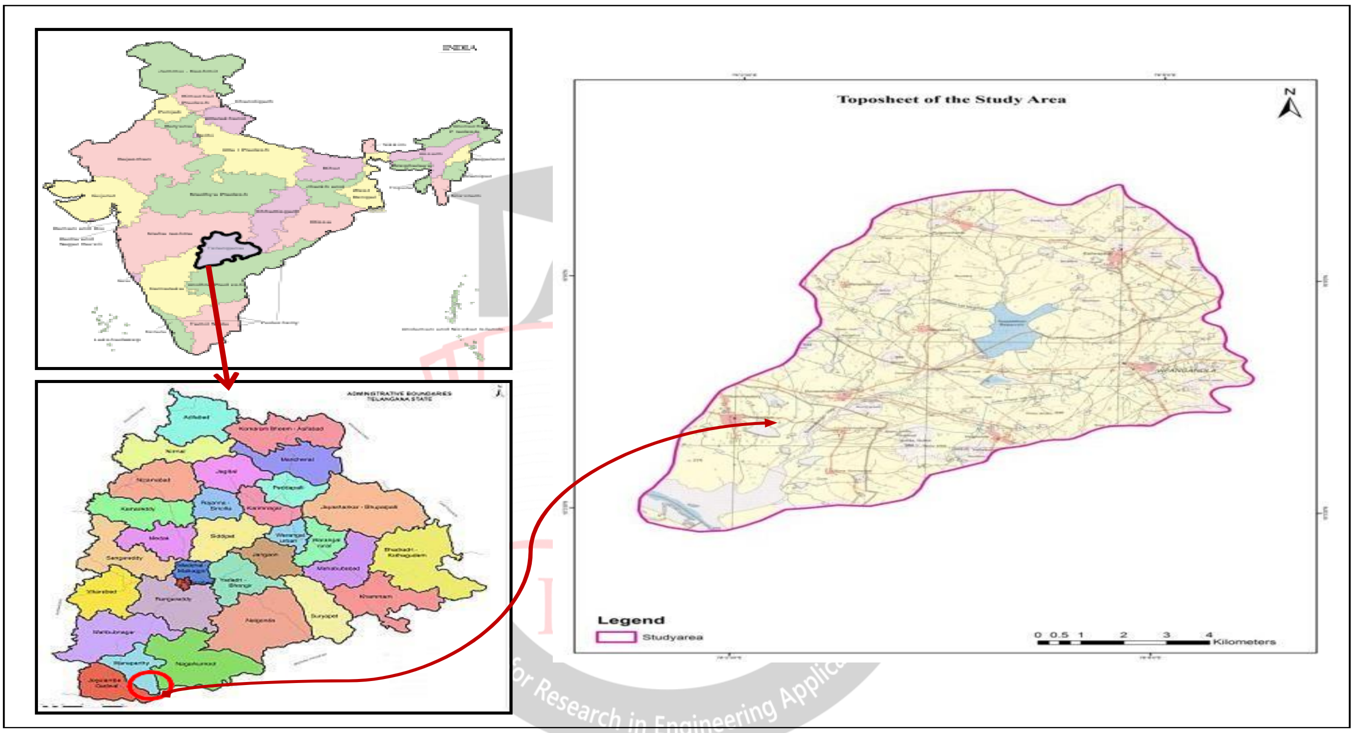


Fig: 1 Location map of the study area

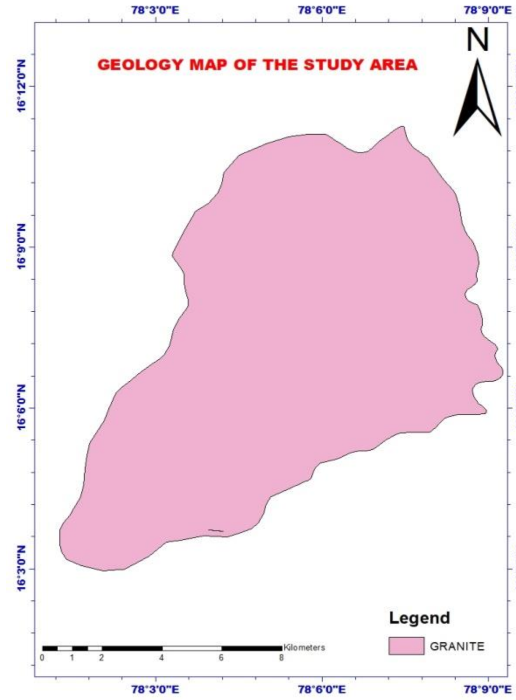
The basin boundaries and drainage network was extracted from SRTM-DEM data with the regional projection WGS-1984, Universal Transverse Mercator (UTM) and 44N Zone. The study area characterized by three types of soils that are Red sandy soil (locally called as dubbasand & chalka), Earthy soils (loamy soil & chalka), Block cotton soil and very little alluvium soils. Geologically the present study area forms a part of the Dharwar Craton of South Indian Shield. In the study area mainly Pink Granite rocks are present (Fig: 2).

The Climate of the present study area is predominantly hot and dry. The average rainfall of the study area is about 1326mm and Temperature goes up to 42^{0}C in summer season and minimum temperature is 17.5^{0}C in winter season. In the study area average depth to ground water level is 3.25m.

Geomorphologically most of the area is occupied by the pediplain complex (Fig: 3).The slope of the ground has significant role in the area's penetration. The slope map (Fig: 4) was divided into five categories: flat (0 - 2.45), mild (2.45 - 6.86), moderate (6.86 – 14.21), steep (14.21 – 22.78) and extremely steep (22.78 – 62.48). The study area has steep slope, whereas the remaing of the area is flat to mildly hilly. The slope differences in a region have a direct effect on the lithological features of the topography. Remote sensing methods enable the analysis of drainage morphometry by providing a synoptic picture of vast regions.

 DOI : 10.35291/2454-9150.2023.0085

ISSN : 2454-9150 Vol-09, Issue-01, Apr 2023



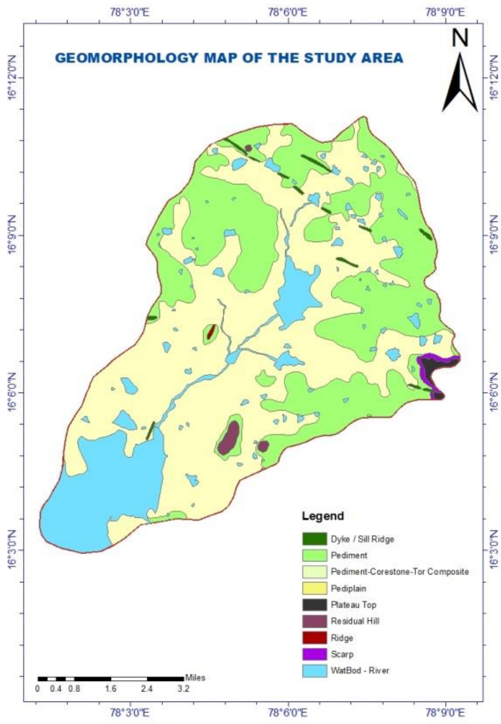


Fig: 2 Geology map of the study area Fig: 3 Geomorphology map of the study area

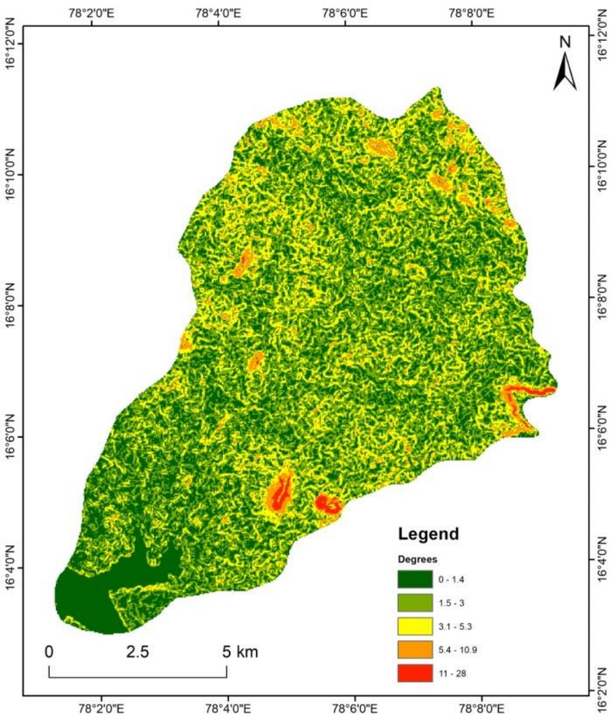


Fig: 4 Slope map of the study area

III. MATERIALS AND METHODS

Manual extraction of drainage network and assigning the stream order from a published Survey of India (SOI) topographic map and from georeferenced satellite data fora large area is a time taking tedious exercise. Extraction of Goverdhanagirivagu basin/watershed boundary and extraction of drainage/stream network from the Goverdhanagirivagu basin using ASTER DEM in conjunction with geocoded standard false color composite remote sensing satellite data and georeferenced SOI Toposheet No 56L/4(E44S4)having 1:50,000 scale using ARCGIS Software. Theextracted basin and stream networks are projected to the regional projection (WGS-1984, UTM zone 44 N). The output of this method is a basis for creating a stream/ drainage network grid with stream order based on Strahler 1964. As pointed out above that Strahler's system of classification designates a segment with no tributaries as a first-order stream. Where two first-order stream segments join, they form a second-order stream segment and so on. The highest stream order in the Goverdhanagirivagu basin was identifiedas fifth order stream. This

 DOI : 10.35291/2454-9150.2023.0085

ISSN : 2454-9150 Vol-09, Issue-01, Apr 2023

technique requires two input model parameters: DEM and a minimum upstream area in hectares, which is the minimum drainage area required to create a stream segment (Magesh et al. 2013). 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 analyzed using the standard mathematical formulae given in Table-1. Drainage map was prepared by on screen digitization using ARC GIS software.

IV. RESULT AND DISCUSSION

The morphometric parameters of Goverdhanagirivagu basin have been calculated and the results are given in the Table-2. The total drainage area of the Goverdhanagirivagu is 122.77 km^2. The whole study area is of Fifth order stream. The drainage pattern of the study area is dendritic in nature and it is influenced by the general topography, geology and rainfall condition of the area. Stream number of the basin decreases with increase in stream order i.e. first order has 187 numbers of streams whereas fifth order has one stream. The total length of stream segments decreases with increase in stream order. First order has stream length of 106.16kms whereas fifth order has stream length of 13.79kms. Mean stream length of study area reveals an increasing trend with the increase in stream order i.e. first order has Mean stream length of 0.57kms whereas fourth order has Mean stream length of 2.59kms. The Stream length ratio of the study area ranges from 1.17 – 2.35. The Bifurcation ratio of the study area ranges from 3 – 4.92 and its Mean bifurcation ratio is 3.76. Drainage density of the study area 1.63/km^2 indicates less permeable materials, sparse vegetation cover and moderate to high relief in the study area.

Table 1 Method of Calculating Morphometric Parameters of Drainage basin

	Morphometric Parameters of Drainage basin		
	MorphometricParameters	Formula/Defination	References
LINEAR	Stream order (U)	Hierarchical order	Strahler,1964
	Stream Length (L_U)	Length of the stream	Hortan, 1945
	Mean stream length(L_{sm})	$L_{sm}=L_u/N_u$; Where, Lu=Mean stream length of agiven order (km), Nu=Number of stream segment.	Hortan, 1945
	Stream length ratio(R_L)	R_L= Lu / Lu-1 Where, Lu= Total stream length oforder (u), Lu-1=The total stream length of its next lower order.	Hortan, 1945
	Bifurcation Ratio(R_b)	R_b = Nu / Nu+1 Where, Nu=Number of streamsegments present in the given order Nu+1= Number of segments of the next higher order	Schumn,1956
RELIEF	Basin relief (B_h)	Vertical distance between the lowest and highest points of basin.	Schumn,1956
	Relief Ratio (R_h)	R_h = Bh / Lb Where, Bh=Basin relief, Lb=Basinlength	Schumn,1956
AERIAL	Drainage density(D_d)	D_d=L/A Where, L=Total length of stream, A= Area of basin.	Hortan, 1945
	Stream frequency (F_s)	F_s=N/A Where, L=Total number of stream,A=Area of basin	Hortan, 1945
	Texture ratio (T)	T=N_1/P Where, N_1=Total number of first orderstream, P=Perimeter of basin.	Hortan, 1945
	Form factor (R_f)	R_f=A/(Lb) Where, A=Area of basin, Lb=Basinlength	
	Circulatory ratio(R_c)	R_c=4πA/P Where A= Area of basin,π=3.14, P=Perimeter of basin.	
	Elongation ratio(R_e)	R_e=√(Au/π)/ Lb Where, A=Area of basin, π=3.14,Lb=Basin length	Schumn 1956
	Length of overlandflow (L_g)	L_g=1/2D_d Where, Drainage density	Hortan, 1945

DOI : 10.35291/2454-9150.2023.0085

Table 2(a) Results of Morphometric Analysis

Sr. no	Parameter	Value
1	Basin Area $(Km)^2$	122.77
2	Perimeter (Km)	49.75
3	Basin order	5
4	Drainage density(D) (Km/Km^2)	1.63
5	Drainage Texture (T)	3.16
6	Stream frequency (F) $(Km)^2$	1.94
7	Relief Ratio (Rh)	0.01
8	Basin Length(Lb) (Km)	18.41
9	Basin Relief(Bh) (m)	129
10	Mean Bifurcation ratio (Rb)	3.76
11	Form Factor (Rf)	0.23
12	Circulatory ratio (Rc)	0.4
13	Elongation Ratio (Re)	1.48
14	Length of overland flow (Lg) (Km)	0.19

Table 2(b) Results of Morphometric Analysis

Streamorder	Numberof streams	Total lengthof stream(Km)	Mean streamlength(MLS)	Stream length ratio(LRS)	Bifurcationratio
1	187	106.16	0.57	2.3 5	4.92
2	38	50.67	1.33	1.6 6	3.8
3	10	22.09	2.21	1.1 7	3.33
4	3	7.78	2.59		3
5	1	13.79	Mean Bifurcation Ratio 3.76		

V. MORPHOMETRIC ANALYSIS

Morphometric parameters have been classified into

1) Linear Aspects
2) Areal Aspects and
3) Relief Aspects

5.1. LINEAR ASPECTS

Linear aspects include stream order, stream number, stream length, mean stream length, stream length ratio and bifurcation ratio and are discussed below:

5.1.1. STREAM ORDER (U)

In the present study, ranking of streams has been carried out based on the method proposed by Strahler (1964). Stream orders are classified up to Fifth orders in the study area. Details of stream order of several tributaries of Goverdhanagirivagu area shown in the Table 2(b). Goverdhanagirivagu could be designated as a fifth-order stream (Fig. 5). The maximum stream order frequency is observed in case of first-order streams and then for second order. Hence, it is noticed that there isa decrease in stream frequency as the stream order increases and vice versa.

 DOI : 10.35291/2454-9150.2023.0085

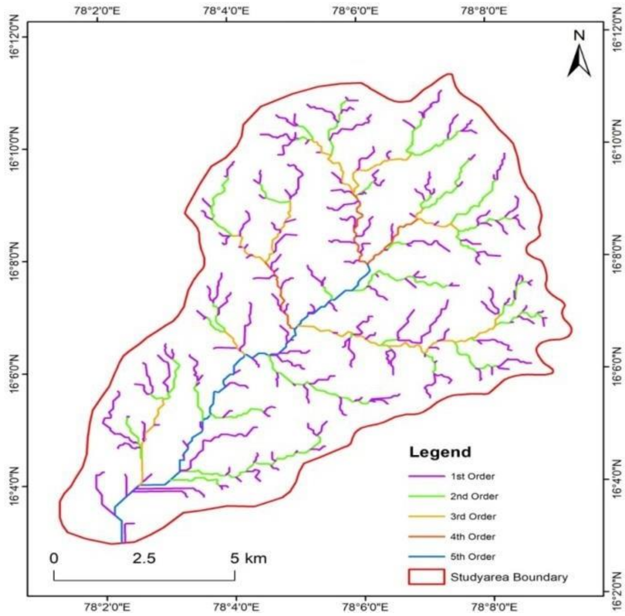
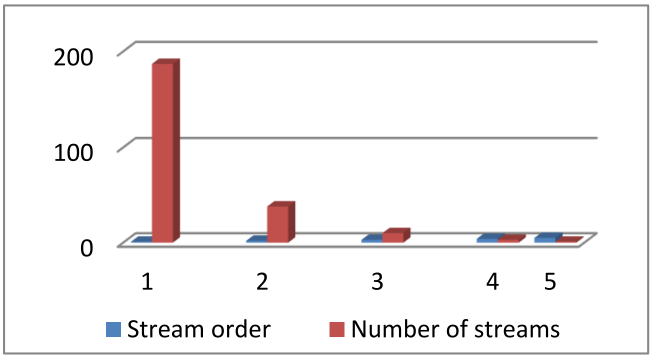


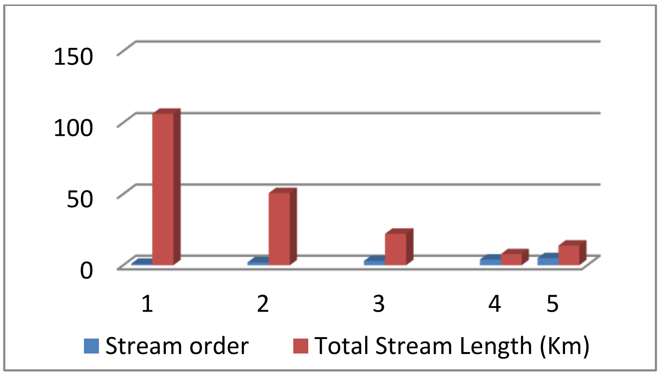
Fig: 5 Drainage Network map of the study area

5.1.2. STREAM NUMBER(Nu)

The count of stream channels in each order is termed as stream order. As per Horton's law (1945) of stream numbers, ''the number of streams of different orders in a given drainage basin tends closely to approximate as inverse geometric series of which the first term is unity and the ratio is the bifurcation ratio''.

According to this law, the number of streams counted for each order is plotted on logarithmic scale on the *y* axis against order on arithmetic scale on the *x* axis (Chat 1). Number of streams of different orders and the total number of streams in the basin are counted and calculated in GIS platforms. During calculation it is identified that the number of streams gradually decreases as the stream order increases; the variation in stream order and size of tributary basins is largely depends on physiographical, geomorphological and geological condition of the region. 239 stream lines are recognized in the whole basin, out of which 187 are first order streams, 38 are second order streams, 10 are third order streams, 3 are fourth order streams and one is fifth order stream(Table 2(b)).





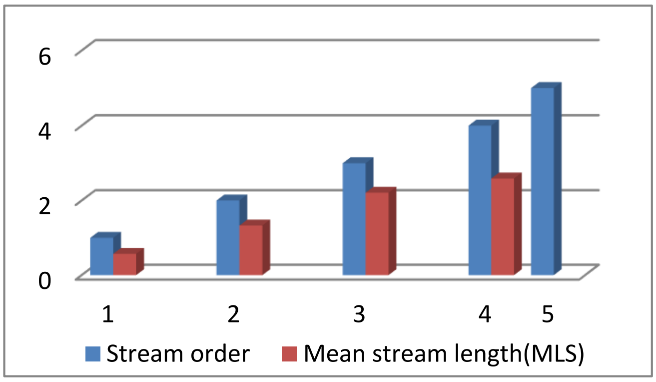
Chat: 1 Stream order of the study area Chat: 2 Stream length of the study area

5.1.3. STREAM LENGTH (Lu)

According to Horton (1945), streams lengths delineate the total lengths of stream segment of each of the successive orders in a basin tend to approximate a direct geometric series in which the first term is the average length of the stream of the first order. The numbers of streams of various orders in the basin are counted and their lengths are measured. In general, the total length of stream segments decreases with increasing stream order (Table 2(b) & Chat: 2).The highest stream length of the basin is 106.16km (1st order) and the lowest is 7.78km (4th order).

5.1.4. MEAN STREAM LENGTH (Lsm)

Mean stream length (Lsm) reveals the characteristic size of components of a drainage network and its contributing surfaces (Strahler 1964). In general, mean length of channel segments of a given order is greater than that of the next lower order but less than the next higher order. Mean stream length of the study area reveals an increasing trend with the increase in stream order. Mean stream length of study area based on stream order is shown in the Table 2(b) & Chat 3.



Chat: 3 Mean stream length of the study area

5.1.5. STREAM LENGTH RATIO (RL)

Horton's law (1945) of stream length points out that mean stream length segments of each of the successive orders of

 DOI : 10.35291/2454-9150.2023.0085

a basin tends to approximate a direct geometric series with stream length increasing towards higher order of streams.

The stream length ratio of the study area ranges from 1.17 – 2.35 (Table 2(b)). This change might be attributed to variation in slope and topography, indicating the late youth stage of geomorphic development in the streams of the study area.

5.1.6. BIFURCATION RATIO (Rb)

Horton (1945) considered Rb as an index of relief and dissection while Strahler (1957) opined that Rb shows only a small variation for different regions with different environments except where powerful geological control dominates. According to Schumn (1956), the term bifurcation ratio (Rb) 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. According to Strahler (1964), the values of bifurcation ratio characteristically ranges between 3.0 and 5.0 for drainage basin in which the geological structures do not disturb the drainage pattern. The Bifurcation ratio for the study area is 3.76 (table 2(b)) which falls under normal basin category and the basin is less affected by structural disturbances.

5.2. AREAL ASPECTS

Areal aspects include drainage parameters such as drainage density, stream frequency, drainage texture, circularity ratio, length of overland flow and constant of channel maintenance which is discussed below.

5.2.1. Drainage Density (Dd)

Drainage density (Dd) is a measure the total stream length in a given basin to the total area of the basin (Strahler 1964). The drainage density of the study area is 1.63 km/km^2, which indicates that study area has a moderate permeable material, sparse vegetative cover and moderate to high relief (Table 2 & Fig 6). Higher drainage density is associated with the basin of weak and impermeable subsurface material, sparse vegetation and high relief. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture, high runoff and erosion potential of the basin area.

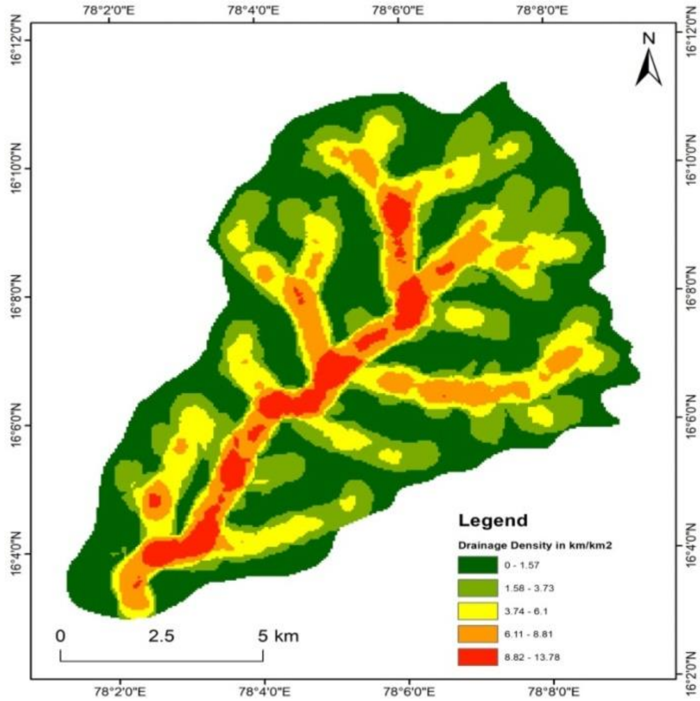


Fig.6 Drainage density map of the study area

5.2.2. STREAM FREQUENCY (Fs)

Stream frequency is the total number of stream segments of all orders per unit area (Horton 1932). Reddy et al. (2004)) stated that low values of stream frequency indicate presence of a permeable subsurface material and low relief. . The stream frequency value of the study area is 1.94 km/ km^2 (Table 2(a)). Stream frequency mainly depends on the lithology of the basin and reflects the texture of the drainage network. The value of stream frequency for the basin exhibits positive correlation with the drainage density value of the area indicating the increase in stream population with respect to increase in drainage density.

5.2.3. DRAINAGE TEXTURE RATIO

Drainage texture is one of the important drainage parameters in morphometric analysis, which indicates relative spacing of drainage lines, which are more prominent in impermeable material compared to the permeable ones. Drainage texture depends upon a number of natural factors such as climate, rainfall, vegetation, lithology, soil type, infiltration capacity, relief and stage of development. 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 soft or weak rocks devoid of vegetation generally exhibit a fine texture, whereas in massive and resistant rocks coarse drainage texture is developed.

The study area has a value of 3.16 which falls under fine drainage texture (Table 2(a)). Sparse vegetation in arid climate causes finer texture than in humid climate.

 DOI : 10.35291/2454-9150.2023.0085

5.2.4. FORM FACTOR (Rf)

Horton (1945) stated form factor as the ratio of the area of the basin and square of the basin length. The value of form factor would always be greater than 0.78 for perfectly circular basin. Smaller the value of form factor, more elongated will be the basin. Rf value of the study area is 0.23 (Table 2(a)). Thus, the study area is elongated one.

5.2.5. CIRCULARITY RATIO (Rc)

Miller (1953) and Strahler (1964) defined circularity ratio (Rc), as the ratio of the area of the basin (A) to the area of a circle having the same circumference as the perimeter (P) of the basin. Circularity ratio (Rc) is influenced by the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin.

The circularity ratio of the study area is 0.40 (Table 2(a)). This value is an indicative of the moderate to low relief and a drainage system that appears to be less affected by structural disturbances.

5.2.6. ELONGATION RATIO (Re)

Elongation ratio (Re) is defined as the ratio of diameter of a circle having the same area as of the basin and maximum basin length (Schumm 1956). It is a measure of the shape of the river basin and it depends on the climatic and geologic types. Elongation ratio value of the study area is 1.48. Higher values of elongation ratio show high infiltration capacity and low runoff, whereas lower Re values which are characterized by high susceptibility to erosion and sediment load.

5.2.7. LENGTH OF OVERLAND FLOW (Lg)

Horton (1945) defined length of overland flow (Lg) as the length of water over the ground before it gets concentrated into definite stream channels. He considered it as one of the most important independent variables affecting hydrologic and physiographic development of drainage basins. The value of Length of Overland Flow of the study area is 0.19 (Table 2(a)). The value is equals to the half of the constant of channel maintenance.

5.3. RELIEF ASPECTS

5.3.1. RELIEF RATIO (Rh)

It rises with declining drainage zone and the overall size of the drainage network. The maximum number of the Relief ratio implies a steep slope with significant relief, while the lowermost value of the Rh suggests a gentle slope with little relief. The relief ratio of the study area is 0.01 which indicates low relief and lower degree of slope.

5.3.2. BASIN RELIEF (Br)

The influence of Br is the most noticeable peak run-off rates and sediment delivery in the study area. The current study area Basin relief is 129m, which indicating that the land has a mild to moderate slope relative to the topography around it.

VI. CONCLUSION

Remote sensing and GIS techniques are convenient tools for morphometric analysis. In the present paper, morphometric analysis of the Goverdhanagirivagu basin, based on several drainage parameters using remote sensing satellite data and latest GIS tools for drainage analysis, has been delineated. Detailed morphometric study of the Goverdhanagirivagu represents dendritic to sub-dendritic drainage pattern with Fifth order drainage. The larger number of first order streams indicate uniform lithology and gentle slope gradient. The bifurcation ratio of the Goverdhanagirivagu is 3.76 which indicate that the basin is normal and the control of drainage network is mainly pronounced by geomorphology. Lower value of bifurcation ratio indicates that the drainage basin is underlined by uniform materials and the streams are usually branched systematically. Goverdhanagirivagu possess high drainage density which is indicative of less permeable material, sparse vegetative cover and moderate to high relief. Circularity and elongation ratio shows that the basin has almost elongated shaped. The whole morphometric analysis shows that the study area has good ground water prospects.

REFERENCES

[1] Agarwal CS (1998) Study of drainage pattern through aerial data in Naugarh area of Varanasi district, U.P. J Indian Soc Remote Sens 26:169–175.

[2] Burrough PA, McDonnell RA (1998) Principles of geographical information systems. Oxford University Press Inc., New York.

[3] Chorley RJ, Schumm SA, Sugden DE (1984) Geomorphology. Methuen, London.

[4] Clarke JI 1996) Morphometry from Maps. Essays in geomorphology. Elsevier publication. Co., New York, PP 235–274.

[5] Cox RT (1994) Analysis of drainage-basin symmetry as a rapid technique to identify areas of possible quaternary tilt-block tectonics: an example from the Mississippi embayment. GeolSoc Am Bull 106:571–581.

[6] Evans IS (1972) General geomorphometry, derivatives of altitude, and descriptive statistics. In: Chorley RJ (ed) Spatial analysis in geomorphology. Harper and Row, New York, PP 17–90.

[7] Evans IS (1984) Correlation structures and factor analysis in the investigation of data dimensionality: statistical properties of the Wessex land surface, England. In: Proceedings of the Int. Symposium on Spatial Data Handling, Zurich. V-1. Geographisches Institute, Universitat Zurich-Irchel. PP 98–116.

[8] Horton RE (1932) Drainage basin characteristics. Am

 DOI : 10.35291/2454-9150.2023.0085

Geophysical UnionTrans 13:350-361.

[9] Horton RE (1945) Erosional development of streams and their drainage basins; hydro physical approach to quantitative morphology. Bull Geol Soc Am 56:275–370.

[10] Hurtrez JE, Sol C, Lucazeau F (1999) Effect of drainage area on hypsometry from an analysis of small-scale drainage basins in the Siwalik hills (central Nepal). Earth Surf Process Landform 24:799–808.

[11] Krishnamurthy J, Srinivas G, Jayaram V, Chandrasekhar MG (1996) Influence of rock type and structure in the development of drainage networks in typical hard rock terrain. ITC J 4(3):252–259.

[12] Krishna N, A. Narsinga Rao and P. Durga Devi (2013) Morphometric Analysis for Hydrological and Denudational Characterization of Geo-Structurally Controlled Sub-Basins: A Study from Godavari and Pranahita Basins, India. SSRG-IJGGS journal, Vol-9 Issue 3, PP: 1-9.

[13] Magesh NS, Jitheshal KV, Chandrashekar N, Jini KV(2012b) GIS based morphometric evauation of Chimmini and Mupily watersheds, parts of Western Ghats, Thrissur District, Kerala. India Earth Sci Inform 5(2):111-121.

[14] Magesh NS, Jitheshal KV, Chandrashekar N, Jini KV(2013) Geographical Information system based morphometric analysis of Bharathapuzha River Basin, Kerla, India. Appl Water Sci:1-11. doi: 10.1007/s13201-013-0095-0.

[15] Merritts D, Vincent KR (1989) geomorphic response of coastal streamsto low, intermediate, and high rates of uplift, Mendocino junction region, northern California. Geol Soc Am Bull 101:1373–1388.

[16] Muller JE (1968) An introduction to the hydraulic and topographic sinuosity indexes. Ann Assoc Am Geogr 58:371–385.

[17] M.L.Waikar and Adithya P.Nilawar, " Morphometric Analysis of a Drainage Basin using Geographical Information System: A Case study," ISSN: 2321-3124, Available at: http://ijmcr.com,vol.2,pp:179-184.

[18] Nag SK, Chakraborty S (2003) Influence of rock types and structures in the development of drainage network in hard rock area.J Indian Soc Remote Sens 31(1):25–35.

[19] Nautiyal MD (1994) Morphometric analysis of a drainage basin, district Dehradun, Uttar Pradesh. J Indian Soc Remote Sens22(4):251–261.

[20] Obi Reddy GE, Maji AK, Gajbhiye KS (2002) GIS for morphometric analysis of drainage basins. GIS lndia 4(11):9–14.

[21] Ohmori H (1993) Changes in the hypsometric curve through mountain building resulting from concurrent tectonics and denudation. Geomorphology 8:263–277.

[22] Praveen Kumar Rai - Kshitij Mohan-Sameer Mishra-Aariz Ahmad-Varun Narayan Mishra (2014) A GIS-based approach in drainage morphometric analysis of Kanhar River Basin, India. Appl Water Sci (2017) 7:217-232.

[23] Reddy OGP, Maji AK, Gajbhiye SK (2004) Drainage morphometry and its influence on landform characteristics in a basaltic terrain, Central India—a remote sensing and GIS approach. Int J Appl Earth Obs Geoinformatics 6:1–16.

[24] Schumm SA (1956) Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. Geol Soc Am Bull 67:597–646.

[25] Schumm SA (1963) Sinuosity of alluvial rivers in the Great Plains. Bull Geol Soc Am 74:1089–1100.

[26] Shreve RW (1969) Stream lengths and basin areas in topologically random channel networks. J Geol 77:397–414.

[27] Strahelr AN (1952) Hypsometric (area-altitude) analysis of erosional topography. Bull Geol, Soc Am 63.

[28] Strahler AN (1957) Quantitative analysis of watershed geomorphology. Trans Am geophysical Union 38:913–920.

[29] Strahler AN (1964) Quantitative geomorphology of drainage basins and channel networks. In: Chow VT (ed) Handbook of applied hydrology. McGraw-Hill, New York, pp 439–476.

[30] Syed Ahmad Ali, Nazia Khan (2013) Evaluation of morphometric Parameters – A Remote Sensing and GIS Based Approach. Open journal of modern hydrology, 2013, 3, 20-27.

 DOI : 10.35291/2454-9150.2023.0085