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Morphometric Analysis of Hard Rock Terrain of Banne Watershed, District Chhatarpur, Madhya Pradesh, India, using Remote Sensing and GIS

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ABSTRACT: Morphometric analysis of a drainage basin gives quantitative information about its total extent. Morphometric parameters represent morphological and physical characteristics which plays an important role in production of hydrological response of the river basin. Watershed used as a logical choice and act as a basic unit in morphometric analysis because all process hydrologic or geologic occurs within the watershed. In the present study, the Banne watershed has been selected which is located in Central part of India and which extends over 756.21 sq km. The study area comprises of hard rock terrain of Bundelkhand region suffering from water scarcity problem since many decades. In present study of Banne watershed, GIS has been used in delineating drainage network using SOI (Survey of India) Toposheets and further has been updated using IRS P6 LISS-III data. Morphological aspects such as linear, areal and relief has been calculated using GIS tool. The main objective of the present study of Banne river watershed is to compute various morphometric parameters and to interpret their behavior on hydrological scenario. Dendritic drainage pattern of the study area suggests the homogeneity of rock. The different morphometric parameters of Banne watershed are calculated in Geographical Information System platform significantly with satellite data and it is found that the study area characterizes with low-infiltration capacity and high-surface runoff. This study will give relevant information for implementing artificial recharge site selection for betterment of groundwater management in the area. Present research work proof to be very beneficial for planners and decision makers for sustainable development and management of the natural resources.

Keywords: Areal aspect, Banne watershed, GIS Morphometric analysis and Relief aspect.

I. INTRODUCTION

A watershed is a natural hydrological entity which allows surface runoff to a defined channel, drain, stream or a river at a particular point [22]. The development of watershed to increase groundwater recharge is becoming an important phenomenon to balance the acute depletion of groundwater level. The deterioration of a watershed is the most common problem in many parts of the world. The major cause of the problem is the mismanagement in land-use activities and unwise use of water resources and its severity varies with geo-hydrological characteristics of an area such as shape of the basin, size, slope, length of the streams, drainage density etc [9, 10].

In past many decades over-exploitation of groundwater has led to the drying up of the aquifers in many parts of the country and for betterment of groundwater status it is essential to implement recharging strategies by conducting morphometric analysis in the drainage basin [13, 19, 20, 32, 33]. Significantly, morphometric analysis of drainage basin is carried out in different parts of the India by different researchers and workers such as, [12,15, 21, 22, 23, 24, 25, 31, 36, 37]. Prioritization of Morphometric analysis is another important step towards prioritizing the sub-basins to find groundwater potential zones and natural resource management strategies [26, 34, 35]. There is a lot of work done in the field of morphometric analysis. On the basis of previous literature very few papers show correlation of geology and geomorphology with assessment of morphometric parameters. The purpose of this study is to bridge the gap left in the previous researches and to connect morphometric parameters analysis with its underlying lithology.

Morphometric analysis of the basin includes qualitative study of the basin area, its perimeter, length of the basin, order of the stream, number of the stream, length of the stream, mean stream length, stream length ratio, drainage density, stream frequency, form factor, circulatory ratio, elongation ratio all these morphometric parameters has been carried out using Arc GIS.

II. STUDY AREA

The present study area of Banne watershed is 756.21 sq km and located between 24° 41′ to 24° 53′ N latitude and 79° 38 ′ to 79° 52′ E longitude. The Banne River originates from southwestern part of Banne watershed and is located at 21.08 Kilometers away from Chhatarpur township area. Main tributary of the Banne River is fed by some small tributaries like Karibarar River, Rota nala and Burhanala. The River flows towards South-East direction and meets the Ken River near Ranguwan village of Chhatarpur district. River Ken is important tributary of River Yamuna. The study area falls in the Survey of India Toposheets No. 54 P/6, 54

P/9, 54 P/10 and 54 P/14with scale (1: 50,000) Fig. 1 shows the location map of the study area.

III. MATERIALS AND METHODS

The main objective of this study is to assess the drainage network of the basin by quantitative morphometric analysis. In the present study, Geo-coded IRS P6 LISS-III satellite data [1], with 23.5 m spatial resolution, downloaded from Bhuvan portal, ISRO, India and SOI toposheets on 1:50,000 Scale has been used for qualitative analysis of various morphometric parameters with its landforms and lithological characteristics of the river basin.

The drainage basin has been digitally traced from SOI toposheets whereas basin boundary has been delineated from SRTM Digital Elevation Model and the database has been updated using IRS-P6 LISS-III satellite image. Digitally traced basin has been divided into eleven sub-watersheds.

Linear and Areal aspects have been calculated using Arc GIS 10.2.2 by considering drainage network and basin analysis of the study area. Relief aspects have been calculated using Digital Elevation Model [1] (DEM) SRTM (30m) considering slope of the study area. Fig. 2 shows the detailed flow chart of methodology of morphometric analysis.

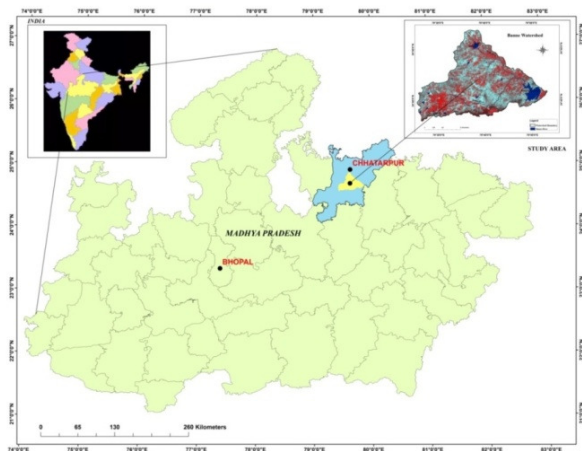

Fig. 1. Study area for Banne River Watershed.

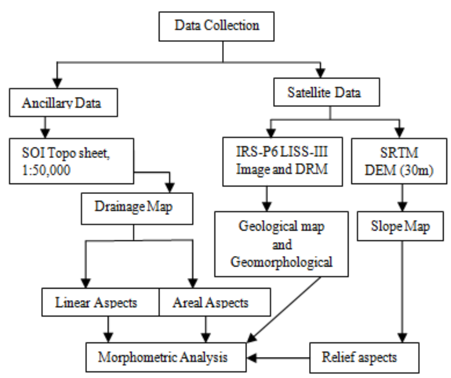

Fig. 2. Flowchart of used methodology.

IV. RESULTS AND DISCUSSIONS

A. Geological Setup

On the basis of interpretation of satellite data and geological field work, the area has been mapped and validated with existing District Resource Map of Chhatarpur district (1:25,000Scale) published by Geological Survey of India.

Granite (Banded Gneissic Complex) of Archaean age, constitute geology of the study area. The major part of the area is occupied by BGC comprising a variety of medium to coarse grained granites, migmatites, gneisses etc. and also contain minor enclaves of schist, phyllites, banded hematite quartzite and metabasics.

Small exposer of NW-SE trending basic dyke is observed in the Northern part of the study area. Intrusive landforms of quartzite in the form of discordant mass of consolidated igneous intrusion that cut across the granite country rock [17, 29]. Such intrusion acts as a barrier as well as carrier and thus controls groundwater flow. These have a groundwater potential on the up-gradient side. Geological map of the study area is presented in Fig. 3.

B. Geomorphology

Geomorphic landforms play pivotal role in setting artificial recharge structures. Geomorphologically, the study area is classified largely as pediment, pediplain, dissected hills and valley and dissected plateau. Pediment occur towards SSE-NNW and SW part of the study area which cover an area of about 225.35 Sq. Kms.

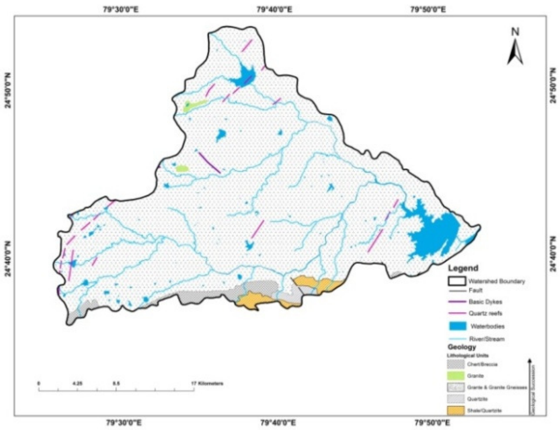

Fig. 3. Geological map.

Major part of the study area is covered by pediplain with an area of about 539.43 sqkm in area whereas dissected hills and valley and dissected plateau occur to southern part of the study area. Dissected hills and valley with relief of bout 380-540 above MSL covered with boulders and sparse vegetation cover. Residual hill is remnant of erosion towards North-eastern part of the study area [1, 17].

Slope influences the surface and subsurface water flow which controls water percolation rate or infiltration, surface runoff and intensity of erosion. Maximum part of the study area of watershed has very gentle slope [1]. Geomorphological map of the study area is shown in Fig. 4.

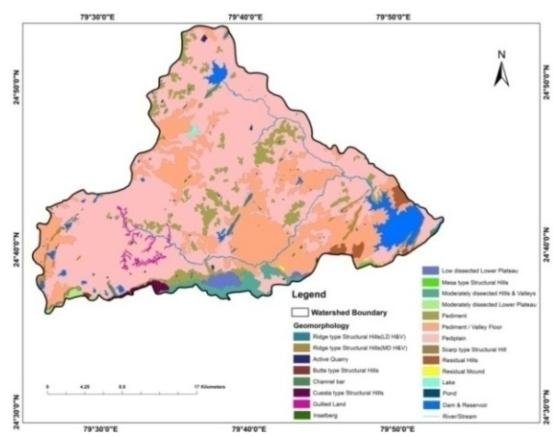

Fig. 4. Geomorphological map.

C. Morphometric Analysis

Morphometry is a measurement and mathematical analysis of the configuration of the Earth surface, shape and dimensions of its landforms [8]. Morphometric analysis of a drainage basin provides important information of a basin. The morphometric analysis is carried out through measurement of various linear, areal and relief aspects of the basin [18]. The measurement of various morphometric parameters involved in the morphometric analysis has been carried out using standard formulae given by many scientists [3, 4, 5, 7]. Figure 5 shows drainage map of the study area.

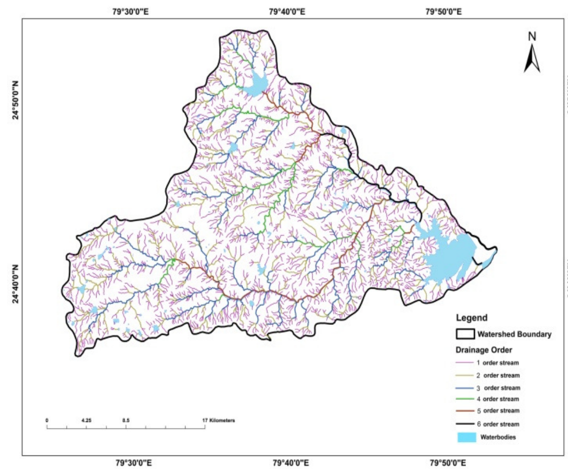

Fig. 5. Drainage map.

Linear Aspects: Linear aspects gives information about one dimensional parameter. Orders of streams are assigned according to hierarchic ordering [7]. In the case of Banne watershed, the highest order of the stream is 6th indicating a moderate size of the watershed. Total number of streams calculated is 2417, total number of 1st order stream is 1893, 2nd order is 418, 3rd order is 86, 4th order streams is 15 and 5th order streams is 4, while 6th order is represented by the single stream. Maximum length of the stream is 23.55 km. Mean stream length (*Msl*) values for Banne watershed varies from 0.55 to 21.26 km.

Bifurcation ratio is 4.52, 4.86, 5.73, 3.75 and 4.0 for 1st to 5th order stream respectively. Bifurcation ratio is considered as index of relief and dissection. The mean bifurcation ratio ranges between 3.0 and 5.0 for basin, which is accompanied by homogeneous lithology with no structural disturbances [3]. Very small range of variation is observed in bifurcation ratio of different regions but it drastically changes in exceptional cases where the region is dominated by its geology [7]. The mean bifurcation ratio for Banne watershed is 4.57 indicates strong structural control on the drainage pattern of the watershed. The details for drainage network analysis are given in Table 1. The perimeter of Banne watershed is 149.09 km and basin length are 36.94 km. Changes in the stream length ratio in the study area from one order to other indicates late youth to early mature stage of the geomorphic development of streams [14]. Stream length ratio of Banne watershed indicates late youth to early mature stage. Rho coefficient exhibits the relation between stream length ratio and bifurcation ratio [3]. According to the report of Quantitative Morphometric Analysis of Shodhganga 'Rho' value calculated for Thoppaiyar sub-basin is 0.80, suggesting higher hydrologic storage. 'Rho' value for Banne watershed calculated as 0.32, 0.54 0.50, 0.50 and 0.82 for order 1st to 5th respectively which discloses that the watershed is having moderate water storage capacity [3].

Areal aspects: Areal aspects deal with information regarding two dimensional parameters of the Basin area. The parameters of Areal aspects are given in Table 2, 3.

Table 1: Details of the drainage network analysis.

Stream order	1st	2nd	3rd	4th	5th	6th
Number of the streams *(Nu)*	1893	418	86	15	4	1
Maximum stream length (km)	2.72	6.17	11.86	11.75	33.31	21.26
Minimum stream length (km)	0.054	0.045	0.13	1.37	1.56	21.26
Total length of the streams *(Lu)* (km) Horton (1945)	1041.29	344.89	187.32	95.02	47.88	21.26
Mean stream length (*Msl*) (km) *Msl = Lu/Nu*	0.55	0.82	2.17	6.33	11.97	21.26
Bifurcation ratio *(Rb)* [Schumn (1956)] *Rb = Nu/N +1* Where, R = Bifurcation Ratio, *Nu* = Total number of stream segments of order , *Nu+1* = Total number of stream segments of next higher order	4.52	4.86	5.73	3.75	4	-
Mean Bifurcation ratio (Rbm)- Average of bifurcation ratio of all orders	4.57					
Stream Length ratio *(Lur)* = $Lm_u/(Lm_{u-1})$ Where, *Rl*= Stream Length Ratio L_{mu} = Mean stream length of order u, L_{mu-1} = Mean stream length of lower order	-	1.49	2.64	2.91	1.89	3.31
Rho Coefficient *(ρ)* [Horton 1945]= *Lur/Rb*	0.33	0.54	0.507	0.504	0.827	-

Table 2: Details of the Basin Geometry.

S. No.	Parameter	Results
1.	Total area of the Basin (A) km²	756.21
2.	Basin Length (Lb) km-Nookaratnam *et al.* (2005)	36.94
3.	Basin Perimeter (P) km -	149.09
4.	Form Factor (Rf) - Horton (1945)	0.55
	Rf = A/Lb² Where, Rf = Form Factor, A = Area of Basin (Km^2), Lb² = Square of the basin length	
5.	Circularity Ratio (Rc) - Miller (1953)	0.43
	Rc = 12.57 X (A / P²) Where, Rc = Circulatory Ratio, A = Area of Basin (Km^2), P = Perimeter of Basin (Km)	
6.	Elongation Ratio (R) - Schumm (1956)	0.84 e
	Re = 2 /Lb X (A /π) Where, Re = Elongation Ratio, A = Area of Basin (Km^2), Lb = Length of the basin (Km), π = 3.14	
7.	Compactness Constant (Cc) - Horton (1945)	1.54 c
	Cc = 0.284 X P/A $^{0.5}$ Where, Cc = Compactness Constant, A = Area of Basin (Km^2), P = Perimeter of Basin (Km)	

Total area of the Banne watershed is 756.21 km^2. Drainage density is a numerical measurement of the dissection of landscape and run-off potential [3]. Drainage density of the Banne watershed is 2.3 Km/Km^2 suggests that the basin is impermeable in nature. Drainage analysis shows that the watershed is dominated by dendritic type of drainage pattern indicating homogeneous country rock. Constant of channel maintenance(C) is the inverse of Drainage density [5]. Value of C for Banne watershed is 0.434 Km^2/Km which in turn indicates low to moderate permeability of rock terrain. Stream frequency is the number of stream segment per unit area [3]. Stream frequency calculated for the study area is 3.19 Km^2 indicates low stream frequency.

Circulatory ratio is 0.43, which indicates youth stage of the tributaries in the basin and is mainly affected by stream frequency, stream length, geological structure, climate, slope, relief and land use/landcover of the basin area [14, 27, 28]. Compactness coefficient of the basin is the ratio of perimeter of sub basin to circumference of circular area, which is equal to the area of the basin [2]. Cc calculated for the study area is 1.54 km.

Horton in 1945, introduced Form factor. Form factor of the Banne watershed calculated is 0.55 which indicates less elongated shape of basin and flow is for shorter duration. Elongation ratio is defined as, the ratio of diameter of a circle of the same area as the basin [5]. Elongation ratio of the study area is 0.84 which suggests that the basin is less elongated with moderate relief.

Drainage texture of the watershed is 7.337 km which is the product of drainage density and stream frequency [3]. Higher value of drainage texture of the basin is fine texture indicates low infiltration rate and high runoff respectively. Texture ratio of the basin is 16.21 km^{-1} such fine texture of the drainage suggests less infiltration and higher soil erosion. Shape factor is reciprocal of form factor which is 1.81.

Length of the overland flow of the watershed is 1.15 Km which is half of the reciprocal of drainage density [3]. Value indicates gentle slope and long flow path, reduced runoff and more infiltration. Lemniscate's value is expressed to determine the slope of the basin [9].

Table 3: Drainage Texture Analysis of the study area.

S. No.	Parameter	Results
1.	Total number of streams (N)	2417
2.	Total length of streams (L)	1737.66 km
3.	Maximum length of stream	33.31km
4.	Maximum stream order	6
5.	Drainage Density (D) - Horton (1945)	2.3
	Dd = L/A Where, Dd = Drainage Density, L = Total stream length of all Orders, A = Area of Basin (Km^2)	
6.	Constant of Channel maintenance (C) C = 1/Dd (Km/Km^2)	0.434
7.	Stream Frequency (F) - Horton (1945)	3.19
	FS = Nu /A Where, FS = Stream Frequency, Nu = Total number of stream segments of all orders, A = Area of Basin (Km^2)	
8.	Texture Ratio (T) - Horton (1945)	16.21
	T = Nu / P Where, T = Texture Ratio, Nu = Total number of stream segments of all orders, P = Perimeter of Basin (Km)	
9.	Shape Factor (Sf) - Sf = 1/Rf Reciprocal of Form Factor (Rf)	1.81
10.	Length of over land flow (Lg) (Km) Horton (1945)	1.15
	Lg = 1/2Dd Where, Dd = Drainage density	
11.	Leminiscate ratio (K) Chorley (1969)	1.80
	K =Lb^2/A Where, Lb = Basin length, A = Area of the basin (Km^2)	

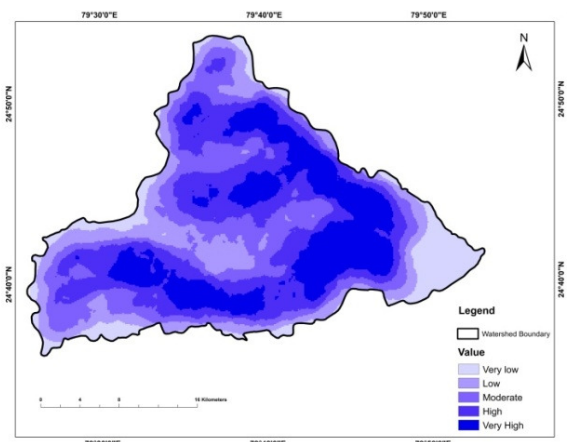

Fig. 6. Drainage Density map.

The Lemniscate's (k) value which is 1.80 suggests maximum area of the basin is accompanied by large number of stream of smaller order.

Relief aspects: Relief aspects are the expression of three-dimensional parameters which influences groundwater potential of the basin. Hydrological perspective of any watershed is determined by channel category and relative gradient of the basin. Parameters of relief aspects of the watershed are given in Table 4. In the study area of Banne watershed, Digital Elevation Model (DEM) of the area (Fig. 7) exhibiting altitudinal variation in the area with maximum elevation observed in the topography is 540 m while the minimum elevation is 220m. Slope plays significant role in controlling the surface and sub surface water flow (Fig. 8). Slope dependent factors associated with basin are water infiltration, surface runoff and intensity of the soil erosion. Southern, South-eastern and South-western region of the study area display steep to moderate slope while Northern, North-eastern and North-western region shows gentle slope of about 1º to 5º slope which is appropriate slope for construction of recharge structures [30].

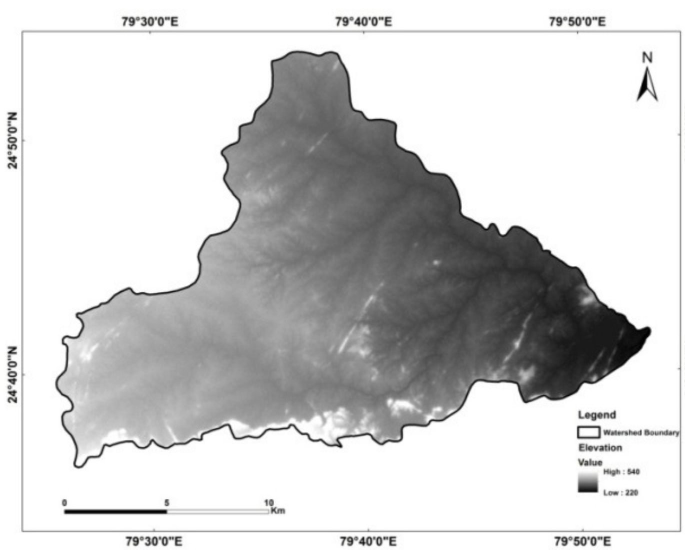

Fig. 7. Digital Elevation Model.

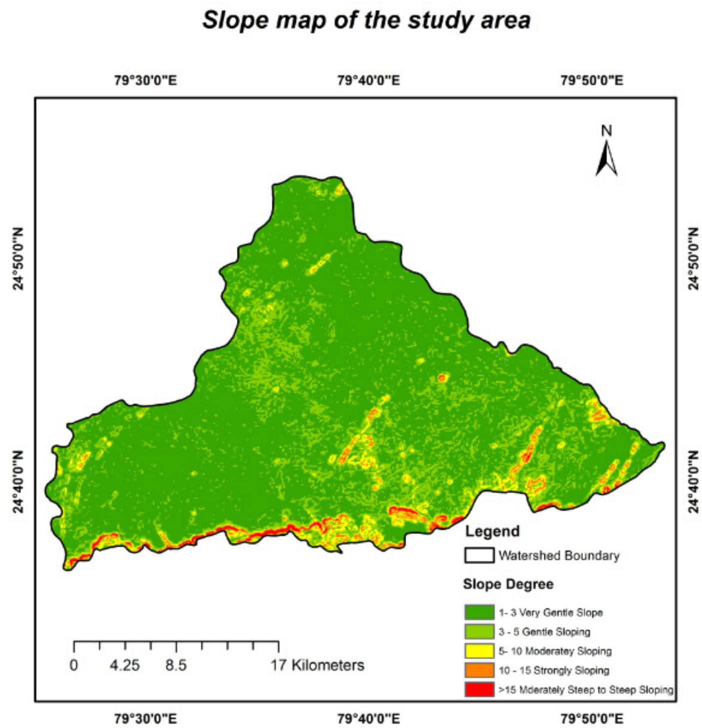

Fig. 8. Slope Map.

Table 4: Relief Characteristics of the study area.

S. No.	Parameter	Results
1.	Height of the highest point on the basin (z)	540 m
2.	Height of the basin mouth (Z)	220 m
3.	Total basin relief (H) meter H = Z – z (Strahler, 1952)	320 m
4.	Relief ratio (Rr) (Schumm, 1956)	0.008
	Rr = H/Lb Where, Rr = Basin relief, Lb = Length of the basin (Km)	
5.	Relative relief ratio (Rhp) (Melton, 1958)	0.21
	(Rhp) = H/P × 100 Where, H= Total Basin relief, P =Perimeter of the basin	
6.	Ruggedness number (Rn) (Strahler, 1956)	0.736
	(Rn) = Rn = R × Dd/1000 Where, R= Basin relief, Dd =Drainage density	
7.	Melton's Ruggedness number (MRn)	11.6
	MRn = Z-z /$A^{0.5}$ Where, 'Z' is maximum elevation, A is Area of the basin, 'z' is minimum elevation within the basin	
8.	Gradient ratio (Rg)	0.008
	Rg = Es – Em/ Lb Where, Es is the elevation at the source, Em is the elevation at the mouth, Lb = Length of the basin (Km)	

Total relief of the basin can be defined as difference between lowest and the highest points of elevation in a basin [3, 7]. Total relief of the Banne river basin is 320 m and Relief ratio is 0.008, and is obtained by considering total relief and basin length. The term Relative relief ratio is introduced by Melton in 1958 and followed by Sreedevi, 1999 concluded that the low values determines less resistant rock [6,16]. Relative relief ratio of the basin is 0.21. Ruggedness number of a basin determines the structure of the terrain. Low value of Ruggedness number of any sub-basin suggests that the area is least affected by the soil erosion [11]. Ruggedness number of the study area is 0.736 implies that the area is more prone to soil erosion. Melton's ruggedness number is 8.1, exhibiting the relation of area and basin relief. Gradient ratio of any basin indicates slope of the channel which helps in the runoff assessment [23]. Gradient ratio calculated for the Banne river basin is 0.008, which reflects that the maximum basin area is associated with low relief.

V. CONCLUSION

Remote Sensing and GIS techniques used in the present study for the analysis of various morphometric parameters, had proved to be the best technique because these are cost effective, less time consuming and error free in determining the nature of bed rock, infiltration capacity, surface runoff, etc. Geologically, the study area is mainly composed of granitic rock. Interrelationship of different morphometric parameters, evaluated through statistical study, helps understand the terrain characteristics of the watershed. Geomorphologically about 497.96 km^2 area of Banne watershed comes under recharge zone.

The basin is drained by stream order from 1st to 6th order. Total 2417 stream segments, in the study area, are sprawling over an area of about 756.21 km^2 and the computed value for stream length ratio indicates late youth to early mature stage of streams. Bifurcation ratio falls in the range of 3.75 to 5.73 which signifies that the drainage pattern of the study area is not twisted out of shape by any geological disturbances.

The value of Rho-coefficient for stream order 1st to 6th is 0.32-0.82 which discloses that the watershed is having moderate water storage capacity. Drainage basin is classified by two important parameters, stream frequency and drainage density which control runoff capacity of surface, yield of sediment and hydrology of the drainage basin. Drainage analysis shows that the watershed is dominated by dendritic type of drainage pattern indicating homogeneous country rock. The computed drainage density of the study area suggests that the basin is impermeable. The calculated value for texture ratio which is 16.21 and the constant for channel maintenance 0.434 km/km^2 which is affected by the drainage density of the watershed these parameters are indicative of very fine drainage texture and low permeability associated with high surface runoff. Hence higher drainage density area represent poor to moderate groundwater potential and low drainage density area shows moderate to excellent groundwater potential. Circulatory ratio of the watershed is affected by the geological structure, land use/landcover, climate, slope, stream frequency, stream length of the basin which is calculated as 0.43. Calculated value for elongation ratio (0.84) and form factor (0.55) of the watershed suggest that the basin is less elongate in shape with moderate relief. Relief parameters of the study area exhibit varied topography with low 220m to high 540m relief. Relief parameters of the study area of Banne watershed clearly suggests mountainous nature of the basin and more prone to soil erosion with less resistant rock. Outcome of the research work suggests that the study area of Banne watershed is in need of urgent planning and management strategies for natural resource management.

VI. FUTURE SCOPE

Morphometric analysis of Banne watershed gives quantitative description and analysis of landforms. Morphometric analysis is an efficient tool for geological and hydrological studies. The present study helps planners and decision maker in land and water management issues. The analysis and results of the present study can be further applied to the drainage basins with similar kind of landforms. Quantitative measurement of the basin through morphometric analysis developed to describe Drainage network, area of the basin, Slope, Relief and other variable. These parameters are correlated statistically which defines drainage basin and channel network characteristics and basin hydrology which further yield results very significantly. The study plays a significant role in understanding the geo-hydrological behavior of drainage basin through its geology, geomorphology and structural scenario. Study also helps in finding geomorphological and structural control of flow and runoff.

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