International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 12 Issue 4 ǁ April 2024 ǁ PP. 120-129

Morphometric Analysis of Watershed in Unchehra Area Satna District of Madhya Pradesh using Remote Sensing and GIS Techniques

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Abstract
This research focuses on morphometric analysis of watersheds utilizing remote sensing and GIS approaches. Geographic information systems (GIS) and remote sensing (RS) techniques are becoming increasingly important because they allow decision-makers and strategists to make more accurate and efficient judgments. Geomorphological processes within a watershed can have an impact on the hydrological availability and scarcity of water. For this reason, in order to ascertain how these activities affect the hydrology of the watershed, a quantitative assessment of its geometry is required. Morphometric study of watersheds is the most effective way for determining the relationships between various characteristics in the research area. GIS and image processing tools used to identify morphological features and assess watershed characteristics. All sub-watersheds have dendritic to sub dendritic drainage patterns with medium drainage texture. The current research is mostly focused with geometry. The order of the stream in the research area ranged from first to fifth order. The change in stream length ratio might be attributed to differences in slope and topographic factors. The variance in bifurcation ratio in the catchment region was attributed to differences in topography and geometric development. The examination of morphometric characteristics such as stream order (NU), stream length (LU), bifurcation ratio (RB), drainage density (D), stream frequency (Fs), circularity ratio (Re), and form factor ratio (Rf) etc. have been assessed. This study shows that morphometric analysis using GIS and remote sensing techniques is an effective tool for hydrological investigations. The current study would benefit various managers and decision-makers in organizations focusing on watershed management and sustainable natural resource management.

Keywords: *Morphometric Analysis, Watershed, Geographic Information Systems, Remote Sensing.*

Date of Submission: 02-04-2024 Date of acceptance: 10-04-2024

I. INTRODUCTION

Morphometric study of watersheds is the most effective way to understand the link between various features in the research area. This study analyse different watersheds under different geomorphological and topographic conditions. A watershed is a region of land in which all water that falls within its bounds drains or flows downhill into a specific body of water, such as a river, lake, or ocean **[2, 25, 36].** Watersheds, or hydrological units, are thought to be more efficient and suitable for performing essential surveys and investigations, as well as planning and implementing different improvement projects such as water and soil conservation, and ensuring their long-term survival **[38].** As a result, watershed management should get special attention to solve water-related challenges **[13].** To understand all characteristics of a watershed, the morphometric parameters including linear, areal, and relief aspects are examined **[19, 26].** The hydrological and geomorphological processes that occur within the watershed provide information on the genesis and evolution of land surface processes **[50].** 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 [**21, 43, 45, 51**]. Geomorphology, Geostructure and drainage pattern within the study area, especially in the hard rock parts of the study area, basin there is a scale in which the river ecosystem functions [**12**].

In combination with traditional data, remote sensing data can be utilized for delineation, ridgeline characterization, prioritizing development issues, evaluating prospects and management requirements, identifying areas susceptible to erosion, creating water-saving plans, researching dams and reservoirs, and other related tasks [**10**]. Remote sensing and GIS methods have been widely employed by scientists to analyze watersheds. Morphometric characteristics give a quantitative catchment report, which is useful in studies like watershed prioritization, hydrologic modelling, natural resource conservation, etc**. [1, 3, 8, 32, 34, 37, 39, 49].** The drainage networks and flowing pattern of a river are complex and vary with time and location due to the effect of the surrounding geology, structural elements, geomorphology, vegetation, and soils **[44].** Streams are studied through the measurement of different properties to perform morphometric studies. To understand the drainage pattern of any area, the topography of that area should first study the drainage map made by a scale so that the direction of flow of the rivers of the study area can be known and further made through watershed. It helps in planning and development and also gives an indication of where the potential ground water can be obtained in the area. Morphometric method is used to tell the main features of drainage in the research area. When the drainage basin attracted the attention of as a result important contributions in the field of drainage studies attention from [**4, 14, 20, 22, 33, 41**]. A systematic examination is important for the planning of a watershed, and its stream courses encompass relief features, linear aspects, and aerial or shape aspects of the catchment **[35].**

II. STUDY AREA

The study area is a part of Survey of India Toposheet No. 63D/10, D/11, D/14, D/15 and it is located between latitude 24°17 00'' to 24°30'00'' North and longitude 80°40' 00' to 80°55' 00" East. It has an area of approximately 800 square km which includes approximately 211 villages (Figure 1). Total estimated population of Unchehra is 18442 and estimated population of Satna is 22,28,935 (2011). Unchehra is in Tehsil Satna headquarter which is situated in the southern part of Toposheet No. 63D and it is situated in the south-west part of Satna district and is located 29 km away from Satna district. Satna is the headquarters of the district as well as the research area. The main villages of this study area are Pallanpur, Paparenga, Regla, Kothi, Bandarha, Pipri Kalan, Akahi, Lagargawan, Dadri, Urdana, Ichol, Bihta, Khuzha, Koniya, Kalpura, Khoh, Itma, Bhatia Khurd, Bhatanwara, Mainaha. The study area can be reached by bus, taxi and train. Satna-Maihar main road is the main road passing through the study area. Unchehra is the nearest railway station to this area. The main line Satna-Jabalpur broad gauge line of West-Central Railway passes through the central part of the district. Hydrogeochemical classification of Vindhyan super group applies to the research area which is unconsolidated soft sandstone and sand. The area is covered with alluvial sand, clay and shale.

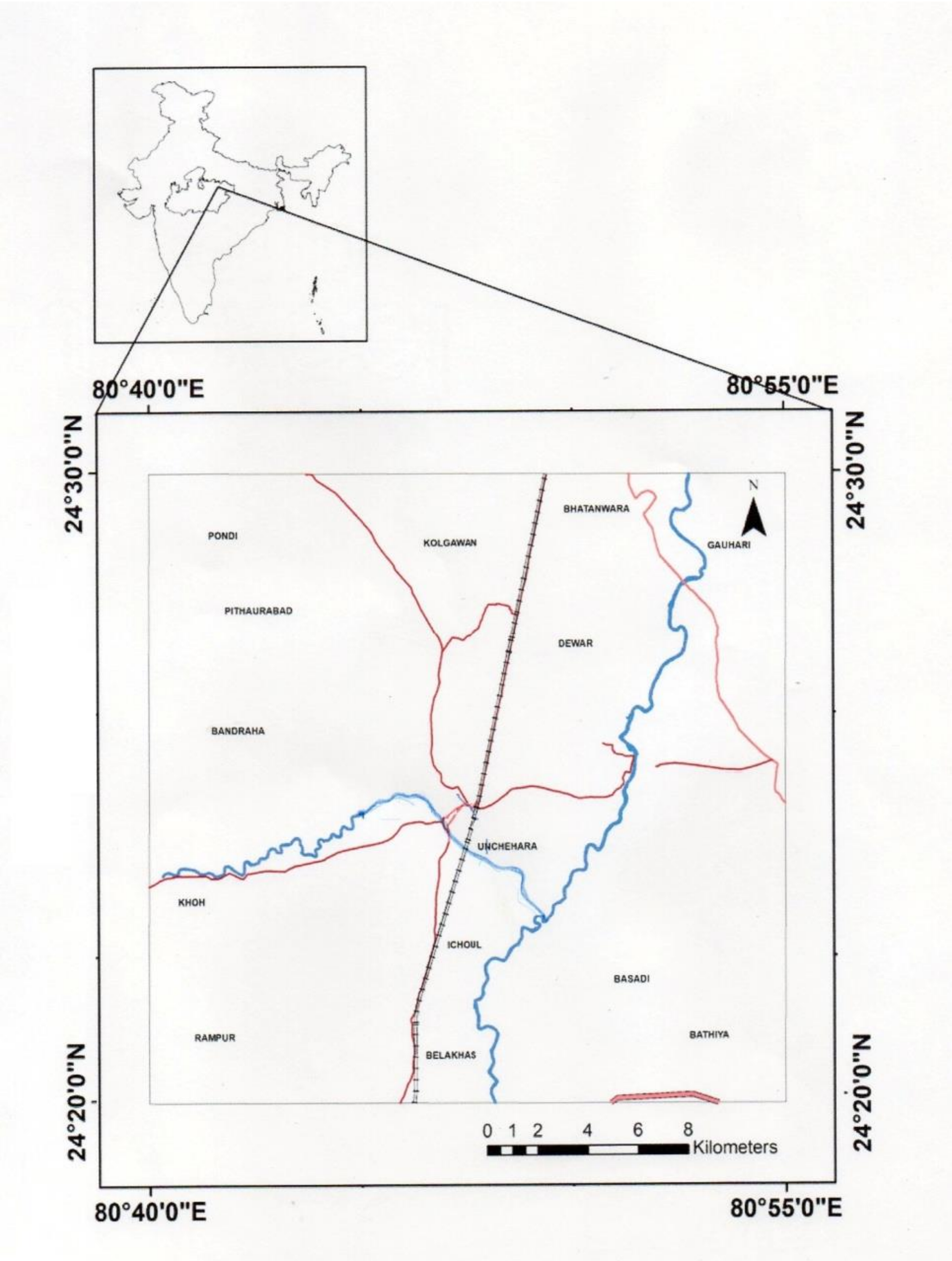

Figure 1: Location of the Study Area

III. METHODOLOGY

The current study technique involves using GIS software to analyze the morphometric aspects of the Unchehra Study area. The required necessary data source for morphometric analysis was carried out using Survey of India toposheet and GIS software. The quantitative analysis of morphometric features in this study considered a variety of morphometric factors such as area, circumference, stream order, stream number, stream length, bifurcation ratio, drainage density, stream frequency, drainage texture, basin length, form factor, elongation ratio, soil flow length, density coefficient, and texture ratio were determined using the method proposed by Horton (1945), Strahler (1964), Schumm (1956), Nukratnam et al. (2005), and Miller (1953). The methods adopted for calculation of morphometric parameters are illustrated in Table 1, and results of computation are illustrated in Table 2.

IV. RESULTS AND DISCUSSION

Quantitative morphometric measurements provide information on the hydrological properties of the watershed. The research area consists of five sub-watersheds. The morphometric analysis was used to select sub-watersheds by considering numerous variables such as the basin's linear aspect, aerial aspect, and relief aspect. Details about the various parameters are mentioned below:

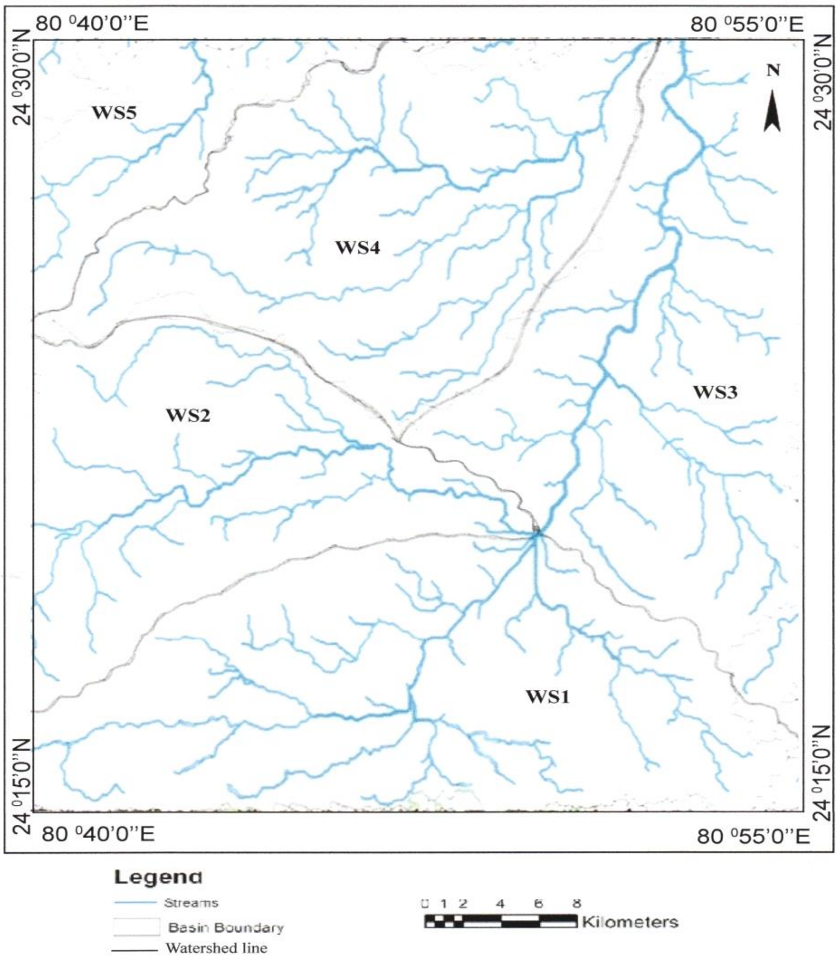

Figure 2: Watershed of the Study Area

(a) Order of Streams and Length of section segments:

The streams in each watershed of the study area were ranked as I, II, III, IV and V orders according to the general method by Horton (1945). When the rivers of the region are studied, the stream with no tributary is given the first rank. A second order current is formed by the combination of two or more first order currents and so on. The fourth order streams in the two watersheds WS1, WS2, WS3 and WS4 are of the highest order. Overall the position of a stream in a sequence of tributaries is measured. The length of the stream is measured for the individual order of each watershed. Rotameters are used to measure the length of these streams. The length is included in the calculation.

(b) Bifurcation Ratio (RB) :

Bifurcation ratio is the ratio of the number of streams of a given order to the number of streams in the next higher order. The bifurcation ratio values in the study area ranged from 1.63 to 2.96 with an average of 2.53 (Table 2). According to Strahler (1964), this indicates that the watershed in the area suffered minimal structural disturbance. Field stuty also confirm this when the water set area is inspected.

(c) Drainage Density (DD) :

Drainage density per unit length and width of the stream. It is obtained by dividing the total stream length and width of the study area by the total basin area. Low drainage density suggests the presence of resistant rocks, vegetation and relief in the area, on the other hand areas with weak and hard material in addition to vegetation and high relief are characterized by high drainage density. The drainage density values for the water set of the area range from 0.565 to 1.777 with an average mean value of 1.502. This work value of the drainage system indicates that the rocks present between the surface medium and the drainage system have good permeability. This is probably due to the karstified nature of the limestone of the area. In general, drainage density is inversely proportional to site flow length and reflects the drainage capacity of a basin. The rates of drainage density of each watershed are calculated and shown in the Table 4.

(d) Stream Frequency (FS):

Stream frequency is the total number of streams per unit study area. Stream frequency is calculated by dividing the total number of streams by the total drainage basin area. The FS values in the watershed ranged from 1.00 to 2.34 with an average of 1.732 (Table 4).

The stream frequency in the study area is calculated by multiplying the stream frequencies with the drainage density. Higher values of the infiltration number indicate less infiltration and more hazard while lower values indicate higher infiltration and less runoff. The number of infiltration for different watersheds of the region ranged between 0.565 to 4.139 with an average of 2.781, which suggests that the region has favorable conditions for recharge of groundwater (Table 4).

(e) Length of Overland Flow (LO):

The overland flow of the study area can be defined as the average horizontal length of the flow path from the divide to the stream in the first order basin. It is approximately one-half inversely proportional to the drainage density [**4**]. Steep rocky areas with less vegetation will produce more runoff than flat plains with more vegetation. Therefore, those with a lower value store more water for a longer period of time, due to which water is absorbed in more quantity. This may be due to the presence of sandstone, limestone and shales in the area at the present time. The study area has drainage parameters but their significance for ground water. It is not mentioned here because of its irrelevance. The length of overland flow different waterhed range from 0.282 to 0.888 with a average of 0.751 present in (Table 4).

(f) Drainage Texture (RT) :

It is stated by Horton (1945) that when groundwater drainage is the total number of parts of all types of stream sequence in a basin and it is very important for geomorphology. Weakness or soft rock formed by the vegetation found in the area helps in the formation of the basin, which leads to the formation of a fine texture, while large blocks and thick rocks lead to the formation of a coarse texture. Vegetation is found far apart in areas with dry climates whereas in areas with humid climates it causes fine texture as compared to vegetation growing on similar rocks. The type of rock formation in an area is generally based on the type of vegetation present and the climate of the area [**9**]. The drainage pattern values of the study area range from 0.652 to 2.00 with an average value of 1.515 (Table 4) which shows very poor drainage texture.

(g) Sinuosity Indices (Si):

The use of sinuosity Indices is related to the channel pattern present in the drainage basin found in the area. The sinuosity Indices is expressed as the ratio of the length of the channel present in the area to the distance to the valley below. It is related to the pattern of drainage in a basin. The study of sinuosity in an area can be helpful in studying the effect of area characteristics on the course of a river. The minimum value of the sinuosity Indices is 1.725 and the maximum is 2.25 (Table 4) and the mean indices value of the area is 1.8908. The rate of sinuosity Indices is given by the erosion pattern of the river present in the area while studying the area. Then from this type of study it seems that the river has reached mature stage from young stage.

(h) Elongation Ratio (Re):

Schumns in (1956) used the elongation ratio to describe the elongation ratio, using the maximum basin length to describe the ratio of the diameter of a circle of a uniform area to the basin of the study area. If the value of elongation ratio in the study area is 0 then it is assumed that it will be in very elongated shape, if the elongation ratio is 1.0 then it is assumed that it will be spherical in shape from which it is known that is, the higher the value of elongation ratio, the more will be the spherical shape of the basin. While on the contrary values between 0.6 and 0.8 are generally associated with high relief and steep ground slopes [**42**]. The elongation ratio in the study area ranges from 0.057 to 0.234, and the average value of the study area is 0.095 (Table 4).

(i) Infiltration Number (If):

The number of watershed found in the study area is reported in terms of drainage density and stream frequency and an opinion is given about the infiltration characteristics of the water sets. The values of infiltration number in the study area range from 0.565 to 4.139, with an average value of 2.781, (Table 2.4) which indicates that the lower the amount of infiltration in the area, the higher the amount of infiltration, and consequently, less runoff in the area, leading to drainage.

(j) Ratio of circularity (Rc):

This ratio has been used as the ratio of the basin area present in the study area to the circle area present in the area as its perimeter basin [**42**]. It is due to the lithological properties present in the study area. The length of the stream present in the area, its frequency, the geological formations present there, the land use present in the area, and the climate found in the study area and the slope of the basin have an effect.

The circulation ratio of the study area ranges from 0.322 to 0.546, with an average value of 0.392 (Table 2.4) which proves that the characteristic of the watershed is less than the medium, which affects the drainage system less, indicating that the characteristic of the sub watershed is there is medium to low relief. The value of the circular ratio present in the region indicates the condition of a basin.

(k) Form Factor (Rf):

The form factor found in study area is a numerical index (Horton, 1932) commonly used to represent individual basin shapes. The length of the narrow basin found in the study area is more, so it is less due to any one factor. Normally the value of form factor is between 0 and 1. The lower the value of the form factor, the greater will be the length of the basin, thus, where the value of the form factor is high, in those basins, their flow is high for a short time, and in those basins, the drainage is for a long time. They are low altitude flows. The form factor values found in the study area range from 0.008 to 0.136 with an average value of 0.034 (Table 4).

(l) Continuous channel maintenance (C):

Shows the need for units of such parameters found in the study area. With the help of such parameter one can determine the area required to maintain linear kilometer of stream channel. In the drainage basins of the study area having higher values of this type of parameter, the density values for the drainage will decrease. High basin channels in general exhibit high permeability of continuous taxonomic rocks and vice versa [**24, 29, 47**]. The continuously maintained channel in the study area ranges from 0.562 to 1.769, with an average value of 0.814 (Table 4), demonstrating the high value of continuously maintained channel, information about high permeability, low to moderate slope and strong control of lithology is obtained.

Table 1: Morphometric Parameters with References

S.N.	Morphometric Parameters	Methods	References
1.	Stream order (U)	Hierarchical order	Strahler, 1964
2.	Stream Number (Nu)	Nu= N1+N2+.....Nn	Horton (1945)
3.	Stream length (Lu)	Length of the stream	Horton 1945
4.	Mean stream length (Lsm)	Lsm=Lu/Nu; where, Lu=Stream length of order 'u', Nu=Total number of stream segments of order 'u'.	Horton 1945
5.	Stream lenghth ratio (Rl)	Rl=Lu/Lu-1; Where, Lu=Total stream length of order 'U', Lu-1=Stream length of next lower order.	Horton, 1945
6.	Bifurcation ratio (Rb)	Rb=Nu/Nu+1; where, Nu=Total number of stream segment of order 'u', Nu+1=Number of segment of next higher order.	Schumn, 1956
7.	Mean Bifurcation Ratio (Rbm)	Rbm=average bifuracation ratio of all orders.	Strahler, 1964
8.	Drainage density (Dd)	Dd=L/A; where, L=Total length of streams, A=Area of watershed	Horton, 1945
9.	Form factor (Rf)	$Rf=A/(Lb)^2$; where, A=Area of watershed, Lb=Basin length.	Horton, 1932

S.N.	Morphometric Parameters	Methods	References
10.	Circularity Ratio (Rc)	$Rc=4\pi A/P^2$; where, A=Area of watershed, π = 3.14, P=Perimeter of watershed.	Miller, 1953
11.	Elongation Ratio (Re)	$Re=2\sqrt{(A/\pi)}/Lb$; where, A=Area of watershed, π = 3.14, Lb=Basin length.	Schumn, 1956
12.	Drainage Texture (Rt)	Rt=Nu/p; where, Nu=Total number of stream of all orders, P=Perimeter of watershed.	Horton, 1945
13.	Length of overland Flow (Lof)	Lof=1/2Dd; where, Dd=Drainage density	Horton, 1945
14.	Constant Channel Maintence (C)	C=1/Dd; where, Dd=Drainage density.	Schumn, 1965
15.	Infiltration Number (If)	If=Fs×Dd; where, fs=Stream frequency, Dd=Drainage density.	Faniran, 1968
16.	Sinousity Index (S.I.)	S.I.=OL/EL; where, OL=Original length, EL=Expected length.	Schumn, 1965
17.	Stream Frequency (Fs)	Fs=Nu/A; where, Nu=Total number of stream of all orders, A=Area of the Basin.	Horton, 1945
18.	Basin relief (Bh)	Vertical distance between the lowest and highest points of watershed.	Hadley and Schumn, 1961
19.	Relief Ratio (Rh)	Rh=Bh/Lb; where, Bh=Basin relief, Lb=Basin length.	Schumn, 1965
20.	Relative Relief (Rr)	Rr=Bh/P; where, Bh=Basin relief, P=Perimeter of watershed.	Melton, 1957
21.	Ruggedness number (Rn)	Rn=Bh×Dd; where, Bh=Basin relief, Dd=Drainage density.	Patton & Baker, 1976

Table 2: Stream order, Number and bifurcation ratio of streams in different watersheds

Water shade No.	Stream order	No. of Streams	Bifurcation Ratio	No. of Stream used	Product of column (3&4)	Weighted Mean
	1	2	3	4	5	6
WS_1	I	39				
	II	15	2.43	54	131.22	
	III	12	1.15	27	31.05	
	IV	04	2.41	14	33.60	
Avg.			1.99			2.06
Total				95	195.87	
WS_2	I	26				
	II	12	2.00	38	76.00	
	III	06	1.71	18	30.78	
	IV	04	1.20	10	12.00	
Avg.			1.63			1.79
Total				66	118.78	
WS_3	I	43				
	II	20	2.04	63	128.52	
	III	02	6.661	22	146.52	2.85
	IV	10	0.18	12	2.16	
Avg.			2.96			
Total				97	277.20	

WS_4	I	31				
	II	13	2.21	44	97.24	
	III	09	1.30	22	28.60	
	IV	02	3.00	11	33.00	
Avg.			2.17			2.06
Total				77	158.84	
WS_5	I	09				
	II	06	1.28	15	19.20	
	III	00	06	06	36.00	
	IV	00	00	00	00	
Avg.			2.42			2.62
Total				21	55.20	

Table- 3: Stream order, Number and bifurcation cumulative stream length in different watershed

Water shade No.	Stream order	Total Stream Length (km)	Cumulative stream length (km)	Total number of stream	Mean stream Length	Maximum Length of the basis (km)
	1	**2**	**3**	**4**	**5**	**6**
WS_1	I	35	35	39	00.89	
	II	15	50	15	01	
	III	06	56	12	00.50	35
	IV	05	61	04	01.25	
WS_2	I	24	24	26	00.92	
	II	14	38	12	01.16	32.5
	III	11	49	06	01.83	
	IV	05	54	04	01.25	
WS_3	I	40	40	43	00.93	
	II	13	53	20	00.65	39
	III	03	56	02	01.50	
	IV	12	69	10	01.20	
WS_4	I	34	34	31	01.09	
	II	18	52	13	01.38	36
	III	09	61	09	01	
	IV	03	64	02	01.50	
WS_5	I	07	07	09	00.77	
	II	06	13	06	01	23
	III	00	13	00	00	
	IV	00	13	00	00	

Table 4: Morphometric Analysis and Shape Parameter of different watershed

Water shade No.	Drainage Density Dd=L/A	Stream frequency Fs=Nu/A	Length of overland flow L of=1/2 Dd	Infiltration number 1f=Dd×Fs	Sinuosity indices Si=OL/EL	Drainage Texture Rt=Nu/P	Form Factors (Rf) Rf=A/(Lb)^2	Circularity Ratio (RC) Rc= 4π A/P^2	Elongation Ratio Re=2 √(A/π/Lb)	Constant of Channel Maintenance L=1/Dd
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
WS_1	01.742	02.00	0.871	03.484	01.74	2.00	0.009	0.358	0.061	0.574
WS_2	1.661	01.55	0.830	2.574	02.25	1.476	0.011	0.386	0.067	0.602
WS_3	1.769	02.34	0.884	4.139	01.725	1.923	0.008	0.322	0.057	0.565
WS_4	1.777	01.77	0.888	3.145	01.882	1.527	0.008	0.348	0.059	0.562
WS_5	0.565	01.00	0.282	0.565	01.857	0.652	0.136	0.546	0.234	1.769
Total	7.514	08.66	3.775	13.907	09.454	7.578	0.172	1.96	0.478	4.072
Average Mean	1.502	01.732	0.751	2.781	01.8908	1.515	0.034	0.392	0.095	0.814

V. CONCLUSION

The watershed analysis carried out of remote sensing and GIS based on morphometric analysis. Hydrogeologically, the topography of the region is undulating and studies indicate that most of the rocks in the region are of quite permeable nature. Rb (bifurcation ratio) values in the study area indicate that there has been minimal structural disturbance to the watersheds. The watershed with low drainage density values suggest moderate runoff and moderate to high permeability of the terrain which may be due to the underlying sandstone. In general, drainage density varies inversely with the length of land flow and indicates the drainage efficiency of a watershed area. The drainage of the basin is mainly of dendritic type which indicates lack of uniformity and structural control in texture. Remote sensing and GIS has given hydrological information and delineation in the terms of the watershed. Digital elevation model (DEM) is efficient tools for the most important aspects of planning and execution for drainage management and hydrological resource development. The morphometric study may be very useful for make strategy for groundwater resource management. In future research, it is advised that social and economic elements be included to gain a more thorough knowledge of sub-watersheds and their importance for management actions.

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