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Research Paper

Morphometric Analysis of Watershed using Geospatial Approach: A Case Study of Nagod Area, Satna District of Central India

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ABSTRACT: *Water resource management is necessary to sustain the living environment in a watershed. Anthropological activity on watersheds can lead to resource imbalances, affecting their functioning. The morphometric analysis of watersheds using GIS and remote sensing techniques is the main emphasis of this study. Decision-makers and strategists are using geographic information systems (GIS) and remote sensing (RS) techniques more and more because they make decisions more effectively and accurately. Morphometric analysis helps in understanding the behaviour of drainage features in response to various hydrological processes such as infiltration, runoff, erosion, and sediment transport. Morphometric analysis of watershed is crucial for studying how drainage basins respond to topological properties. This knowledge is useful for scientific planning and management of watershed. Remote sensing and geographical information systems are useful instruments for detecting such changes in the watershed, whether caused by natural processes or human intervention. To determine the relationships between various characteristics in the research area, the most effective way istho ugh morphometric analysis of watersheds. Morphometric characteristics linear, aerial and relief 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 all been investigated. This study demonstrates that morphometric analysis with GIS and remote sensing methods is a useful tool for hydrological investigations. The current study would be useful to decision-makers and managers in organizations that emphasize watershed management and sustainable natural resource management.*

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

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I. INTRODUCTION

Remote sensing and geographic information systems (GIS) have revolutionized the field of water resource research [39]. Remote sensing and GIS methods have been widely employed by scientists to analyze watersheds. 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 [29]. As a result, watershed management should get special attention to solve water-related challenges [9]. 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, 20, 25]. To understand all characteristics of a watershed, the morphometric parameters including linear, areal, and relief aspects are examined [13, 22]. The hydrological and geomorphological processes that occur within the watershed provide information on the genesis and evolution of land surface processes [41]. Morphometric characteristics give a quantitative catchment report, which is useful in studies like watershed prioritization, hydrologic modelling, natural resource conservation, etc. [1, 3, 5, 23, 25, 28, 30, 38].Morphometric study of watersheds is the most effective way to understand the link between various features in the research area. This study analysedifferent watersheds under different geomorphological and topographic conditions. 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 [15, 34, 35, 36, 37, 42].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 [8].

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[6].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 [35]. 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 attention was drawn to the drainage basin, significant contributions were made in drainage studies [4, 10, 14, 16, 24, 33]. 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 [26].

II. STUDY AREA

The study area is a part of Survey of India Toposheet No. 63D/5, D/6, D/7, D/9,D/10and D/11 it is located between latitude 24°24'27.004"to 24°49'2.438" North and longitude 80°21'53.171"to 80°45'59.835" East. It has an area of approximately 831 square km (Figure 1) which includes approximately 240 villages. Nagod, also known as Nagaud, is a town and nagar panchayat in Satna district, Madhya Pradesh, India. It is located 27 kilometers from Satna city. It is the administrative center of Nagod Tehsil. Nagod is close to the district headquarters in Satna and well-connected by road. Nagod was home to 22,568 people according to the 2011 India census. Males constitute 53% of the population and females 47%. The location is easily accessible via road. The climate ranges from semi-arid to humid, with an average rainfall of around 1000 mm. Summer temperatures can reach 46^{0}C, while winter temperatures can drop to 4^{0}C. Humidity levels can reach 75% during the rainy season. Hydrogeochemical classification of Vindhyan super group applies to the research area which is unconsolidated materials. The study area topography is characterized by Bhander and Rewa group of rocks. In general, the soils in this research region are red, yellow, and alluvial; they are also yellowish to reddish-brown in color, drained to well-drained, and have a moderate to high infiltration capacity. Agriculture and Forest are the primary land-use patterns.

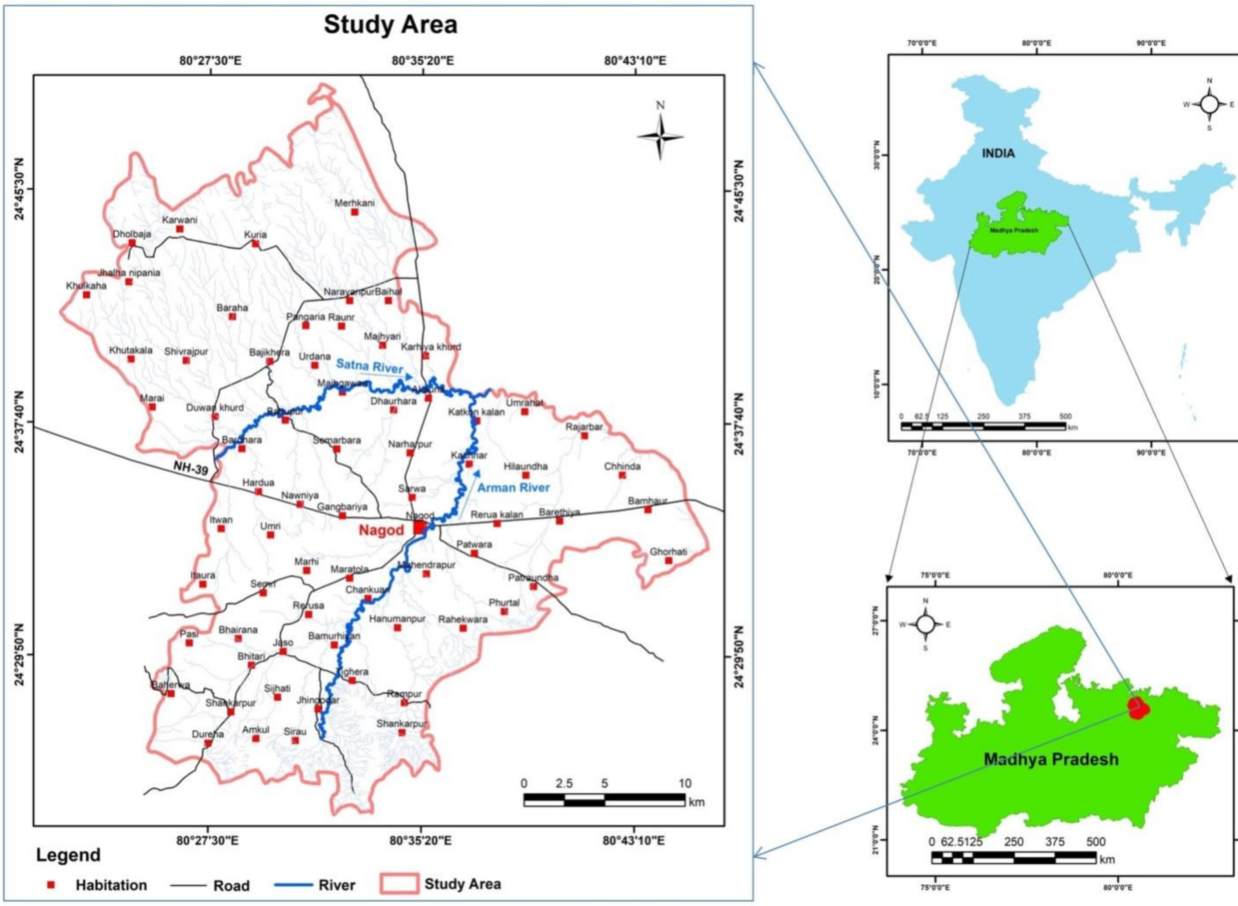

Figure 1: Location of the Study Area

III. METHODOLOGY

The contemporary study technique involves using GIS technology to analyze the morphometric aspects of the Nagod Study area. The required necessary data source for morphometric analysis was carried out using Survey of India toposheet and GIS software. The mosaic tool in ArcGIS was then used to cut and combine the georeferenced toposheets into a single composite toposheet that covered the research area. The watershed's stream network has finally been obtained by digitizing the combined toposheet. A lot of work and time are required to complete the morphometric study on the digital drainage network. Stream ordering, naming, and merging/splitting at suitable points are time-consuming processes, even with advanced computational tools like GIS.The quantitative analysis of morphometric features in this study considered a variety of morphometric factors such as area, perimeter, stream order, stream number, stream length, bifurcation ratio, drainage density, stream frequency, drainage texture, basin length, form factor, elongation ratio, texture ratio, etc. were determined using the method proposed [11, 12, 16, 24, 32, 33]. The formulas utilized for the quantitative measurement of morphometric parameters are explained in Table 1 and spatially the sub watershed for the study area is shown in figure 2. All of the study was done using ArcGIS software within the Geographic Information System environment.

Table 1. Formula for computation of morphometric parameters

PARAMETERS	FORMULA'S	REFERENCE'S
Linear Aspects (La)		
Stream order (U)	Hierarchical rank	Strahler (1964)
Number of Streams (Nu)	$Nu= N_1+N_2…+N_n$	Horton (1945)
Stream length in km (Lu)	$Lu= L_1+L_2….+L_n$	Horton (1945)
Mean stream Length (Lsm)	Lsm = Lu / Nu	Strahler (1964)
Bifurcation Ratio (Rb)	Rb = Nu/Nu+1	Schumm (1956)
Stream length Ratio (RL)	RL = Lu / Lu-1	Horton (1945)
Mean Bifurcation ratio(Rbm)	Avg. of Rb ratio of all orders	Strahler (1964)

Aerial Aspects (Aa)		
Basin Length (Lb)	$Lb=1.312*A^{0.568}$	Nookaratnam et al. (2005)
Circulatory Ratio (Rc)	$Rc= 4\pi A/P^2$	Miller (1953)
Compactness Constant (Cc)	$Cc= 0.2821*P/A^{0.5}$	Horton (1945)
Drainage density (Dd)	Dd = Lu /A	Horton (1932)
Drainage Intensity (Di)	Di = Fs / Dd	Faniran (1968)
Drainage Texture Ratio (T)	T= Nu/P	Horton (1945)
Elongation Ratio (Re)	$Re= (2/Lb)*(A/\pi)^{0.5}$	Schumn (1956)
Form Factor (Rf)	$Rf= A/Lb^2$	Horton (1945)
Infiltration Number (If)	If = Fs * Dd	Faniran (1968)
Length of overland flow (Lo)	Lo = 1 / Dd*0.5	Horton (1945)
Stream frequency (Fs)	Fs = Nu/A	Horton (1932)
Relief Aspects (Ra)		
Basin relief in m (H)	H = Z - z	Strahler (1957)
Relief ratio (Rh)	Rh = H / Lb	Schumm (1956)
Ruggedness Number (Rn)	Rn=Dd*(R/1000)	Melton (1957), Strahler (1964)

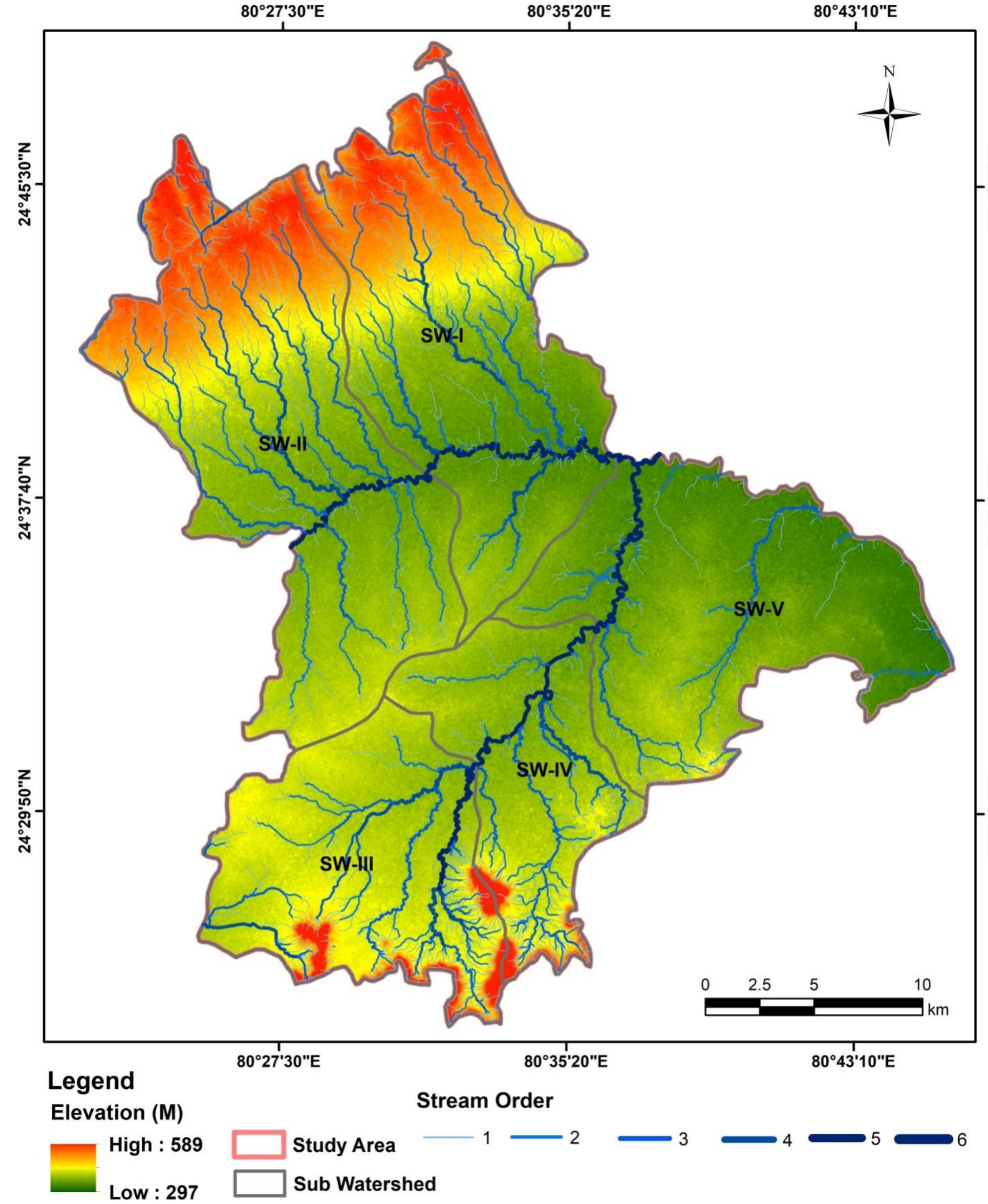

Figure 2: Watershed of the Study Area

IV. RESULTS AND DISCUSSION

Quantitative morphometric measurements provide information on the hydrological properties of the watershed for the study area. The morphometric analysis was carried out by considering numerous variables such as the basin's linear aspect, aerial aspect, and relief aspect. The study revealed that the watershed area varies from the minimum of 98.64 km^2 at SW-IV with the maximum of 228.07 km^2 at SW-II. Watershed perimeter (P) signifies the boundary size of watersheds, with the perimeter ranging from the smallest being 54.36 km in SW-IV up to the largest of 89.21 km at SW-II, followed by next SW-III, SW-V and SW-I. Details about the various parameters are shown in table 2, 3 & 4 and description are mentioned below:

4.1 LINEAR ASPECTS

4.1.1 Stream Order

The initial stage of any watershed analysis is stream ordering. The approach suggested by Strahler has been used in this study to ordering the streams. Watersheds have a dendritic drainage pattern, indicating homogeneous underlying strata and absence of structural tectonic control. Stream order and number indicate moderate altitude and minimal lithological variation.

4.1.2 Stream length

Stream length is the most significant characteristic in a drainage basin. The stream lengths of all five sub-watersheds were estimated using the law given by Horton. According to Horton's law, decreasing stream order leads to an increase in stream length. This indicates that the first order stream has a maximum length.. This describes the permeability of rock formations in a watershed area. The difference in stream flow might be due to high elevation, lithological changes, or relatively steep slopes. Stream length indicates hydrological qualities and bedrock arrangement of the area. In general, porous bedrocks and depleted watershed are associated with a more modest stream number and longer stream length. The present study reveals the longest stream length of 349.15 km at SW-II and shortest of 153.76 km at SWV. Tables 2 and Figure 2 show the stream lengths of five sub-watersheds for the study area.

4.1.3 Mean Stream length

Strahler identified stream length as a parameter of drainage network components within watershed. In general, greater stream order indicates longer stream length, whereas lower stream order indicates shorter stream length. The mean stream length is shown in Table 3.

4.1.4 Stream length ratio

The stream length ratio compares the mean stream lengths of one order to the next lower order of stream segments. Stream length ratios vary between sub-watersheds in the research area, with no consistent trend. The shift in slope and topography suggests a late stage of geomorphic development in the study area's streams.

4.1.5 Bifurcation ratio

The bifurcation ratio in a drainage network refers to the number of stream segments in a particular order compared to the next higher order in a basin [24]. In the presented study, Rb values are highest at 18.76 in SW-IV and lowest at 13.86 in SW-V, respectively. The values of bifurcation ratio are presented in Table 3. Bifurcation ratio indicate that the area has moderately to very mountainous, has a moderate ground slope, moderate to high runoff, and moderate bed rock permeability. This suggests that the structural disruptions have not had an impact on the watershed drainage pattern.

Table 2. Sub-watershed wise input morphometric parameters for the study area

Sr. No.	Details of Sub Watershed	Basin Area (A) (km^2)	Perimeter (P) (km)
1.	SW-I	193.26	85.17
2.	SW-II	228.07	89.21
3.	SW-III	134.26	57.41
4.	SW-IV	98.94	54.36
5.	SW-V	176.44	74.91

Table 3. Linear Aspect of morphometric parameters for the study area

Sub Watershed (SW)	Stream Order						Mean Bifurcation ratio
	I	II	III	IV	V	VI	
SW I							
No. of stream (Nu)	208	41	10	3	1	-	3.87
Stream length (Lu)(km)	156.24	83.25	37.04	16.15	17.61	-	

Mean stream length (km) (Lsm)	0.75	2.03	3.70	5.38	17.61	-	
Stream length ratio(km) (Rl)	0.53	0.44	0.44	1.09	0	-	
Bifurcation Ratio (Rb)	5.07	4.10	3.33	3.00	0	-	
SW II							
No. of stream (Nu)	194	47	13	3	1	-	3.77
Stream length Lu (km)	164.27	86.2	76.88	9.94	11.86	-	
Mean stream length (km) (Lsm)	0.85	1.83	5.91	3.31	11.86	-	
Stream length ratio(km) (Rl)	0.52	0.89	0.13	1.19	0	-	
Bifurcation Ratio (Rb)	4.13	3.62	4.33	3.00	0	-	
SW III							
No. of stream (Nu)	233.00	60.00	15.00	4.00	1.00	-	3.91
Stream length Lu (km)	128.36	48.61	42.91	21.62	9.77	-	
Mean stream length (km) (Lsm)	0.55	0.81	2.86	5.41	9.77	-	
Stream length ratio(km) (Rl)	0.38	0.88	0.50	0.45	0	-	
Bifurcation Ratio (Rb)	3.88	4.00	3.75	4.00	0	-	
SW IV							
No. of stream (Nu)	171.00	43.00	9.00	1.00	1.00	-	4.69
Stream length Lu (km)	88.20	42.78	31.45	7.56	12.25	-	
Mean stream length (km) (Lsm)	0.52	0.99	3.49	7.56	12.25	-	
Stream length ratio(km) (Rl)	0.49	0.74	0.24	1.62	0	-	
Bifurcation Ratio (Rb)	3.98	4.78	9.00	1.00	0	-	
SW V							
No. of stream (Nu)	97.00	23.00	3.00	0.00	2.00	1.00	2.78
Stream length Lu (km)	68.01	47.99	21.38	0.00	15.23	1.15	
Mean stream length (km) (Lsm)	0.70	2.09	7.13	0.00	7.62	0.87	
Stream length ratio(km) (Rl)	0.71	0.45	0.00	0.00	0.08	0	
Bifurcation Ratio (Rb)	4.22	7.67	0.00	0.00	2.00	0	

4.2 AERIAL ASPECTS

4.2.1 Drainage density (Dd)

Horton introduced drainage density. This statement indicates the tight spacing of channels. It demonstrates landscape analysis, runoff potential, and infiltration rate, weather conditions, and vegetation cover. High drainage density occurs due to weak or impermeable underlying material, mountainous topography, and limited vegetation. High drainage density results in finer drainage texture, whereas low drainage density results in coarser texture. Drainage density is classified into four classes: low (<2), moderate (2-4), high (4-6), and extremely high (>6). Drainage density provides a numerical measure of landscape segmentation and run-off potential [41]. A drainage density value of almost 0 indicates a permeable basin with strong infiltration rates and groundwater potential. According to Nautiyal, areas with limited drainage density may have extremely resistant permeable subsoil beneath dense vegetation and low relief [18].

4.2.2 Stream Frequency (Fs)

The total number of streams in the study area is known as stream frequency [12]. Lower and greater drainage densities are associated with stream frequencies. Drainage frequencies vary between sub-watersheds in the research area. Sub watersheds III and IV have more than 2 per km^2. The majority of first- and second-order streams in many areas are seasonal, meaning that they form along hill slopes during the rainy season as a result of heavy downpours. After the rainy season, they dry up and resemble gullies, with the depth and width increasing during the next rainy season.

4.2.3 Drainage Texture ratio

Texture ratio refers to the spacing of drainage lines. According to Horton, it refers to the total number of stream segments per area boundary [12]. Smith defines drainage texture as the number of stream segments of all kinds per area perimeter [31]. The texture of a drainage basin varies based on temperature, rainfall, rock type, relief, and stage of development [12, 31]. Low drainage density results in coarse drainage texture, and high drainage density produces fine drainage texture. Smith defined texture ratio as the proximity of one stream to another [12].

4.2.4 Circulatory ratio (Rc)

Millerdefines circulating ratio as the ratio of a basin's area to that of a circle with the same perimeter [16]. The circularity ratio is controlled by factors such as geological features, climate, terrain, land cover, stream length, and basin slope. The circularity ratio is controlled by factors such as geological features, climate, terrain, land cover, stream length, and basin slope. Table 4 shows that the circulation ratio for the sub-watershed ranges from 0.03-0.51, indicating that the tributaries in the basin are in their youth stage.

4.2.5 Elongation ratio (Re)

The elongation ratio is calculated by dividing the diameter of a circle with the same area as the drainage basin by its greatest length [24]. According to Reddy et al. and Yadav et al., a basin with a greater elongation ratio suggests active denudation, high infiltration capacity, and minimal runoff, whereas a lower elongation ratio indicates higher elevation and headward erosion along tectonic lines [22, 40]. The study area has an average elongation ratio of 0.60, indicating lower peak flow over longer durations and an extended basin form. The ratio ranges from 0.59 to 0.63.

4.2.6 Form Factor (Rf)

Form factor defined as the ratio of basin area to basin length squared, according to Horton [11]. For a study area, the form factor shows the basin's flow intensity. The value of the form factor is between 0 and 1. The more elongated the basin's shape, the smaller the form factor value. The form factor reflects the flow intensity of a basin within a specific region. The form factor value ranges from 0 to 1. The smaller the form factor, the more extended the basin. In this studied area, the form factor ranges from 0.28 to 0.31 (Table 4). The drainage of the watershed has a flatter peak flow over time and an extended form with lower values.

4.2.7 Compactness constant (Cc)

According to Horton (1945), it is the ratio of basin perimeters to circle perimeters divided by the same watershed area. The method compares hydrologic basins to circular basins of equal area. The compactness constant (C) varies based on factors such as lithology, permeability, climate, plant cover, relief, and erosion duration. Higher Cc levels in a basin correlate with increased permeability of its rocks, and vice versa [19].

4.2.8 Length of overland flow

Horton definition of overland flow refers to the distance water travels before settling into specific stream courses [11]. The length of overland flow (Lo) is equal to half of the reciprocal of drainage density [12].According to Horton, this is a crucial independent variable that impacts the drainage basin's hydrology and physiography. Table 4 displays overland flow lengths by sub-watershed.

4.2.8 Infiltration Number

Infiltration is a measure of the soil's ability to transport water into and through its profile. Soil temporarily holds water, allowing it to be used by roots, plants, and soil creatures. The infiltration number, which is calculated by drainage density and drainage frequency, provides information on the rate of infiltration as well as impermeable bedrock and high relief places in the watershed.

RELIEF ASPECTS

4.3.1 Basin Relief

Basin relief provides insight into the geomorphic processes and landforms of a watershed under consideration. This morphometric parameter provides insight into the basin's denudational properties, governs stream gradient, and influences surface runoff and sedimentation.The lowest point is 161 m, and highest point is 259 m and moderate slope and moderate runoff.

4.3.2 Relief Ratio

As the drainage area and watershed size decrease, the relief ratio tends to increase. The largest relief ratio indicates steep slope and considerable relief, whereas a lower relief ratio suggests low degrees of slope. Relief ratio for the study area is different for various for sub watershed-I to V are 6.17, 6.94, 12.22, 14.08 and 5.09, respectively. Relief ratio helps to understand where to establish settlement and afforestation also for agricultural opportunities.

4.3.3 Ruggedness Number

According to Strahler, the ruggedness number is calculated by combining the basin's relief and drainage density into a single quantity [32, 33]. Strahler, describes ruggedness number (Rn) as the product of maximum basin relief and drainage density and it usually combines slope steepness with its length.

Table 4. Aerial and Relief Aspect of morphometric parameters

Parameters	SW I	SW II	SW III	SW IV	SW V
Aerial Aspects (Aa)					
Drainage Density (Dd)	1.61	1.53	1.87	1.84	0.87
Basin Length (Lb)	26.08	28.65	21.20	17.83	24.77
Stream Frequency (Fs)	1.36	1.13	2.33	2.27	0.71
Drainage Texture ratio (T)	3.09	2.89	5.45	4.14	1.68
Form Factor (Rf)	0.28	0.28	0.30	0.31	0.29
Circulatory Ratio (Rc)	0.33	0.36	0.51	0.42	0.39
Elongation Ratio (Re)	0.60	0.59	0.62	0.63	0.60
Compactness Constant (Cc)	1.73	1.67	1.40	1.54	1.59
Drainage Intensity (Id)	0.85	0.74	1.25	1.23	0.82
Length of overland flow (Lo)	0.31	0.33	0.27	0.27	0.57
Infiltration Number (If)	2.18	1.73	4.36	4.19	0.62
Relief Aspects (Ra)					
Basin Relief (R)	161.00	199.00	259.00	251.00	126.00
Relief ratio (Rr)	6.17	6.94	12.22	14.08	5.09
Ruggedness Number (Rn)	0.26	0.30	0.48	0.46	0.11

V. CONCLUSION

The watershed analysis carried out of remote sensing and GIS based on morphometric analysis. Hydrogeologically, the topography of the study area is undulating and studies indicate that most of the rocks in the area 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 usefulfor make strategy for groundwater resource management.In future research, it is suggested that social and economic elements be included to gain a more thorough knowledge of sub-watersheds and their importance for management actions. The watershed drainage density, stream frequency, and infiltration number imply moderately permeable subsoil with strong runoff. High basin relief and roughness indicate higher peak discharge and low sediment output per unit area.The study's findings demonstrated that the geospatial approach is a useful tool for identifying and ranking sub-watersheds in a big river basin so that its hydrological and sedimentary features can be better understood.

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