International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 13 Issue 7 ǁ July 2025 ǁ PP. 42-51

Morphometric Analysis of the Gopad River Sub-basin, Sidhi District, Madhya Pradesh, using Remote Sensing and GIS Techniques

*Sana Siddique, **Bhartendu Mishra
**Department of Geology, PM College of Excellence, Govt. Model Science College Rewa, Madhya Pradesh, India*
***ICV College Jawa, District Rewa, Madhya Pradesh, India*

ABSTRACT: *This study focuses on the morphometric analysis of the Gopad River sub-basin, situated within the Son basin in Sidhi District, Madhya Pradesh, India, using remote sensing (RS) and Geographic Information System (GIS) techniques. Morphometric analysis is a crucial approach to understanding the hydrological behavior of a watershed by examining its geometric characteristics. The study area is divided into six sub-watersheds, and various linear, aerial, and relief parameters have been assessed to determine their influence on drainage patterns and hydrology. The stream order in the study area ranges from first to four, exhibiting a dendritic to sub- dendritic drainage pattern with a medium drainage texture. Variations in bifurcation ratio and stream length ratio are attributed to differences in topography and slope. The morphometric parameters analyzed include stream order (Nu), stream length (Lu), bifurcation ratio (Rb), drainage density (Dd), stream frequency (Fs), circularity ratio (Rc), and form factor (Ff). The results indicate that the low bifurcation ratio and drainage density suggest minimal structural disturbances, while the overall terrain is gently sloping. Additionally, lineament analysis highlights the region's groundwater resource potential. Sub-watersheds have lower drainage densities, making them suitable for artificial recharge. This research demonstrates that ArcGIS and RS techniques provide an efficient and reliable approach for watershed analysis, facilitating better hydrological assessment and water resource management. The findings will be valuable to managers and decision-makers involved in watershed and sustainable natural resource management.* *Keywords: Morphometric Analysis, Watershed, ArcGIS, Gopad River.*

Date of Submission: 02-07-2025 Date of acceptance: 12-07-2025

I. INTRODUCTION

Rivers are the lifelines of ecosystems, shaping landscapes and providing invaluable resources to human societies. The Gopad River, nestled within the Son Basin in the Sidhi District of Madhya Pradesh, India, embodies the intricate interplay between natural processes and human activities. Morphometric analysis, a fundamental aspect of hydrological research, offers a systematic approach to understanding river basin characteristics, aiding in effective watershed management and sustainable development strategies.

The Gopad River Sub-basin, a crucial component of the larger Son Basin, presents a compelling case study for morphometric analysis due to its ecological significance and socio-economic relevance. By meticulously examining various morphometric parameters such as drainage density, stream order, basin shape, and relief ratio, this study seeks to decipher the underlying geological and hydrological processes shaping the Gopad River Sub-basin. Moreover, the analysis aims to elucidate the impact of anthropogenic activities on the basin's morphology, offering insights into the sustainability of current land use practices and informing conservation efforts.

Morphometric analysis gives a quantitative description of basin geometry to help explain beginning slope or inequalities in rock hardness, structural controls, recent diastrophism, and the geological and geomorphic history of the drainage basin (Staler 1964). A watershed is a naturally occurring hydrological unit that, at a specific location, permits surface runoff to enter a designated channel, drain, stream, or river. It is the fundamental component of the water supply that changes with time. Watersheds are defined differently by various workers. Catchment or drainage basin are terms used to describe watersheds in foreign literature. Measuring linear characteristics, channel network gradients, and drainage basin contributing ground slopes is necessary for morphometric analysis (Nautical, 1994). Remote sensing and GIS techniques using satellite images are convenient tools for morphometric analysis. Satellite remote sensing has the ability to provide a synoptic view of large areas and is very useful in analyzing drainage morphometry.

The image interpretation techniques are less time-consuming than the ground surveys, which, if coupled with limited field checks, yield valuable results. Using remote sensing techniques, several investigators have completed morphometric analyses. Srivastava (1997) used remote sensing technologies to investigate the drainage pattern of the Jharia coalfield (Bihar). Nag (1998) carried out morphometric analysis of the Chaka sub-basin in Purulia district, while Nags and Chakraborty (2003) deciphered the influence of rock types and structures in the development of drainage networks in hard rock areas. There are dendritic drainage streams. It is a rain-fed region, with maize and wheat being the principal crops. The hills are covered with reasonably deep forest. The current study aims to investigate and identify multiple drainage parameters in order to get a better understanding of watershed morphology for water resource conservation and management, as well as future hydrological research.

II. STUDY AREA: -

The study area is located in the Sidhi district of Madhya Pradesh, India. The total area is approximately 639.43 km². In Survey of India Toposheet No. 63H/15 and 63H/16, it is located between latitude $24^{0}00'$ to $24^{0}15'$ N and longitude $81^{0}45'$ to $82^{0}00'$ E. The region is irrigated by the Gopad River and its tributaries. The Gopad River is a tributary of the Son River; it originates from the Sonhat plateau. The climate of the study area The Gopad River is a tributary of the Son River; it originates from the Sonhat plateau. The climate of the study area is tropical. The study area is underlain by the Lower Vindhyan Supergroup; a greater part is occupied by sandstone, shale, and limestone. There are some hillocks and undulating lowlands, which define the topography of the study area. The study area finds excellent development of various natural resources like thick forest cover, minerals (bauxite, dolomite, etc.), and alluvial soil with fertility and agriculture in lowlands. Mineralogy, the solubility of rock-forming minerals, and pollution activities all have a significant impact on the kind and quantity of total dissolved solids in natural water. These days, GIS and remote sensing applications are important resources for drainage basin studies. Consequently, the morphometric parameters of drainage features and the borders of watersheds have been established using ArcGIS software.

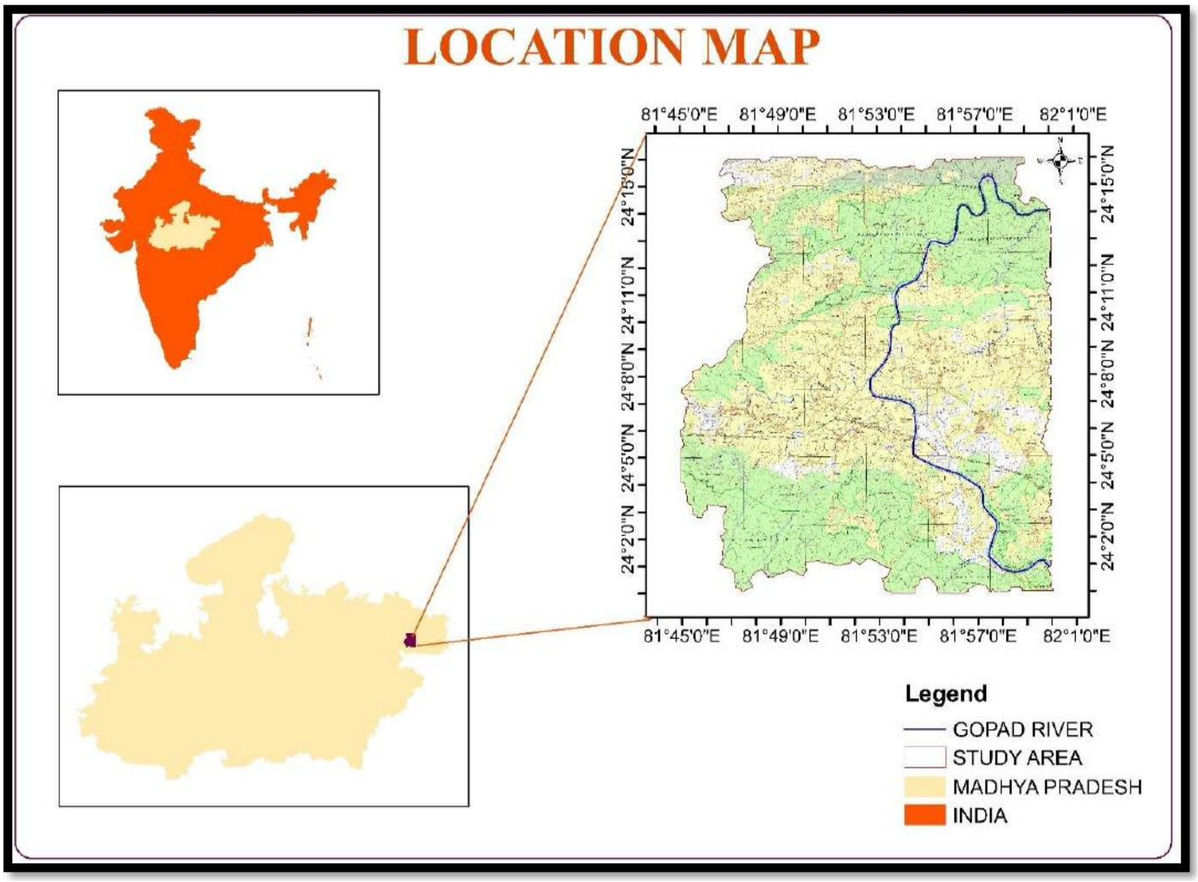

Figure. 1: - Location Map

III. METHODOLOGY: -

Watershed delineation and morphometric analysis of a drainage network need the delineation of all streams, which were accomplished in a GIS context using the ASTER 30 m digital elevation model (DEM). The elevation details that were obtained using ASTER DEM to depict the drainage overlay and the research area's continuous topographic change are shown in Fig. 2. ArcMap 10.1 was used to digitize and georeference topographic data using UTM. Watershed boundaries and drainage lines were obtained from toposheets and DEM using ArcGIS 10.1. For the basin, DEM and contour maps were also produced. The ArcGIS 10.1 software's spatial analyst capabilities were mostly utilized to calculate the basin's aspect, relief, and slope. The various morphometric parameters, such as area, perimeter, stream order, stream number, stream length, bifurcation ratio, drainage density, stream frequency, drainage texture, length of basin, form factor, circulatory ratio, elongation ratio, length of overland flow, compactness coefficient, and texture ratio, were computed based on the formula suggested by Horton (1945), Strahler (1964), and Schum.

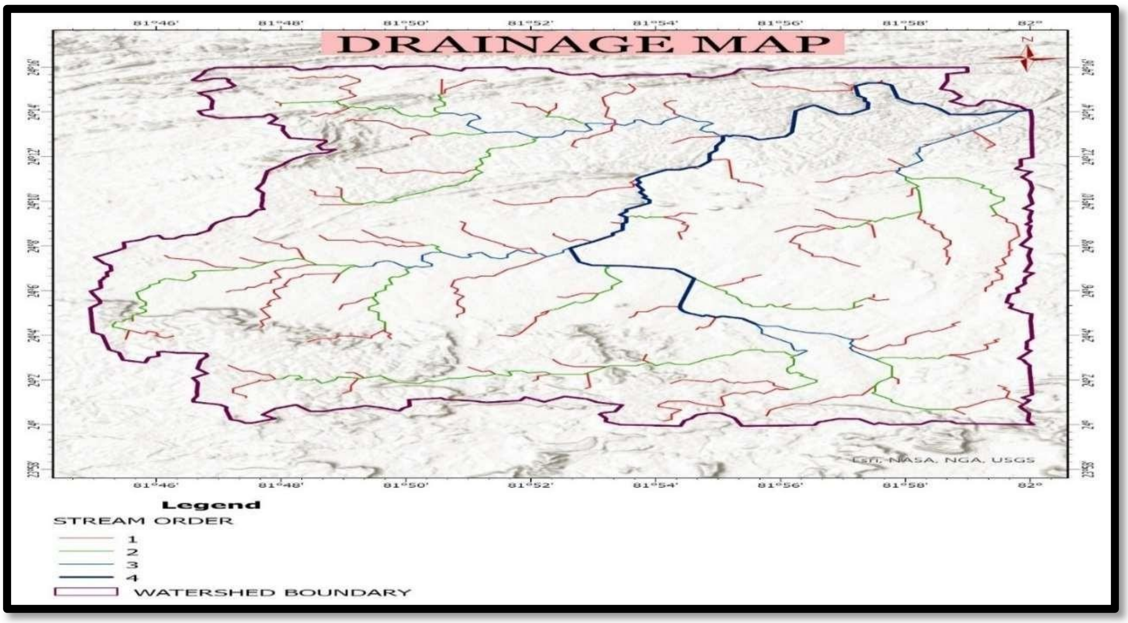

Figure. 3: - Drainage Map

Table 1: Parameters used for the morphometric analysis with references

Morphometric Parameters	Formula	References
Linear Aspects (La)		
Stream Order (U)	The smallest permanent streams are known as "first order". Two first order streams merge to make a larger, second order stream;two second order streams join to form a third order, and so on. Smaller streams joining a higher-ordered stream do not modify its order number.	Strahler, 1964
Total No. of Stream (Nu)	Nu = N1 + N2 +…. Nn	Horton, 1945
Stream Length (Lu)	Length of the stream. Lu = L1 + L2……. + Ln	Horton, 1945
Mean Stream Length (Lsm)	Lsm = Lu / Nu Where, Lu = Mean stream length of a given order (km). Nu = Number of stream segment.	Horton, 1945
Stream Length Ratio (RL)	RL= Lu / Lu-1 Where, Lu = Total stream length of order(u). Lu-1 = The total stream length of its next lower order.	Horton, 1945
Sinuosity Index (SI)	SI=AL / EL	Schumm, 1956
	Where, AL= Actual length of stream, EL= Expected straight path of the stream.	
Bifurcation Ratio (Rb)	Rb = Nu / Nu+1 Where, Nu = Number of stream segments, present in the given order. Nu+1 = Number of segments of the next higher order.	Schumm, 1956
Aerial Aspects		
Drainage density (Dd)	Dd = L / A Where, L = Total length of stream. A = Area of basin.	Horton, 1945
Texture ratio (T)	T = N1 / P Where, N1 = Total number of first order stream, P = Perimeter of basin.	Horton, 1945

Stream frequency (Fs)	Fs = N / A Where, L= Total number of streams. A = Area of basin.	Horton, 1945
Form factor (Rf)	$Rf = A / (Lb)^2$ Where, A = Area, Lb = Basin length	Horton, 1945
Elongation ratio (Re)	$Re = \sqrt{(Au/\pi)} / Lb$ Where, A = Area of basin, $\pi = 3.14$. Lb = Basin length.	Schumm, 1956
Circulatory ratio (Rc)	$Rc = 4\pi A / P^2$ Where, A = Area, P^2 = Square of perimeter.	Miller, 1953
Length of overland flow (Lg)	Lg = 1 / 2Dd Where, Dd = Drainage density.	Horton, 1945
Relief Aspects		
Basin relief (Bh)	Vertical distance between the lowest and highest points of basin.	Schumm, 1956
Relief ratio (Rh)	Rh = H / Lb Here, Bh = Basin relief, Lb = Basin length.	Schumm, 1956
Ruggedness Number (Rn)	Rn = Bh - Dd Where, Bh = Basin relief, Dd = Drainage density.	Schumm, 1956

IV. RESULTS AND DISCUSSION

A detailed morphometric analysis of the research region and numerous characteristics of the Gopad River sub-basin were conducted. The elevation range of the research area is 250 meters above mean sea level, where the maximum elevation of the area is 567 meters and the minimum elevation is 203 meters. Which provides ideal slopes for drainage development. The drainage network was created using ArcGIS software and Aster DEM, and it flowed following the slope. Morphometric examination of drainage reveals the physical properties of watersheds that are valuable for environmental and hydrological research. The essential characteristics of the Gopad River sub-basin are provided in Table 2.

Table 2: Parameters of the Gopad River Sub-basin

Name of area	Basin Area (Km^2)	Perimeter (Km)	Basin Length (Km)
Gopad River Sub Basin	639.65	138.26	51.49

The morphometric parameters can be roughly categorized into three groups: (1) linear aspects, (2) areal aspects, and (3) relief aspects of the basin. The drainage characteristics of the watersheds, considering linear, areal, and relief aspects of the basin, are discussed in the following sections:

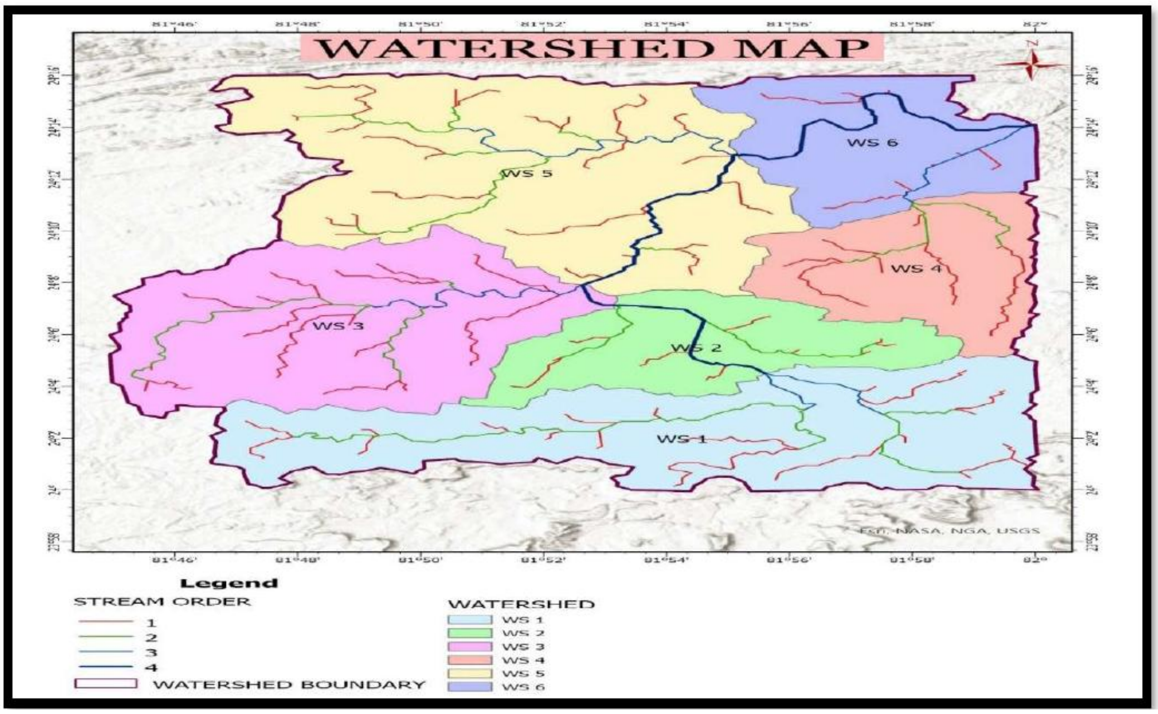

Figure. 3: - Watershed Map

Table 3: - Basin Area (A) of different watershed

S.Nu.	Sub Watershed	WS-I	WS-II	WS-III	WS-IV	WS-V	WS-VI	TOTAL
1.	**Basin Area (A) (km^2)**	174.78	62.35	127.28	143.07	63.94	68.00	639.65

4.1. Linear Aspect (La)

4.1.1. Stream order (U):

Stream order is a classification system used to determine the hierarchy of stream networks based on the arrangement of tributaries. Various methods for stream ordering exist, including the methods of Strahler (1952), Scheidegger (1965), and Horton (1945). This study applies Strahler's method, which is straightforward and incorporates modifications to Horton's system. In this approach, the smallest unbranched streams are first-order, and when two first-order streams join together, they form a second-order stream. Similarly, two second-order streams join together to form a third- order stream, and this pattern continues. When streams of different orders join, the higher order is retained. The study area comprises six stream orders, with first-order streams having the highest number, which gradually decreases as the order increases. The highest order streams in watersheds WS1, WS2, WS3, WS5 and WS6 are fourth order streams and WS4 is third order stream as shown in Table 4 and Figure 3.

4.1.2. Stream Length (Lu):

Stream length is one of the noteworthy features of the watershed, as it discloses surface runoff characteristics. The stream length is computed based on the law proposed by Horton (1945). Streams of comparatively smaller lengths. shows that the area has good slopes, and longer lengths are indicative of a flatter slope. Generally, the total length of stream segments is highest in the first order and lower in the next successive order, as presented in Table 4.

4.1.3. Mean Stream Length (Lsm):

The mean stream length is calculated by dividing the overall length of a stream order by the number of streams in that order. The average stream length of a channel is a dimensional parameter that reflects the distinctive size of drainage network components and their contributing basin surfaces (Strahler, 1964). The mean stream lengths increase with the increase in order. But some basins show opposite relations; a higher-order stream has a small mean length. The mean stream length is shown in Table 4.

4.1.4. Stream Length Ratio (RI):

The Stream Length Ratio (Rl), reflecting the ratio of mean stream lengths between successive orders, varies widely across the six sub-watersheds, indicating geomorphic immaturity and evolving drainage patterns. Values range significantly, such as in WS-I (2.22 to 5.45) and WS-V (0.10 to 10.90), pointing to irregular stream development. Sub-watersheds with fewer stream orders (e.g., WS-II, WS-VI) show limited data, possibly due to low relief or high infiltration. Overall, the inconsistent Rl values suggest a geomorphologically active and structurally diverse region, important for understanding watershed behavior and informing future land and water management strategies.

4.1.5. Bifurcation ratio (Rb):

Strahler (1957) defined the bifurcation ratio as the ratio between the number of streams of one order to the number of streams in the next higher order. In morphometric analysis, it is used to describe the branching pattern of networks like river systems or vascular structures. A low bifurcation ratio indicates a highly branched network, while a high ratio reflects a more linear, tree-like pattern with fewer branches. This measure is widely used in hydrology and geography to assess the complexity and efficiency of flow or distribution systems. The average bifurcation ratios of the watershed catchments, as shown in Table 4, indicate some variation. The overall average value of 2.26 (Table-5) suggests that while there is minor structural control in some areas, most of the drainage network has developed through natural geomorphic

4.2. Aerial Aspects (Aa):

4.2.1. Drainage Density (Dd):

Drainage density (DD) is an important morphometric parameter that represents the total length of streams per unit area in a watershed. It reflects the extent of landscape dissection and helps in understanding surface runoff characteristics. In this study, DD values for six sub-watersheds range from 0.13 to 1.39 km/km², with an average of 0.596 km/km² (Table 5). Higher DD values, such as in WS-5 (1.39) and WS-2 (0.87), indicate a well-developed, dense drainage network, commonly found in areas with steep slopes, low permeability soils, and high runoff. These conditions promote faster water movement and limited infiltration. Conversely, lower DD values in WS-4 (0.13) and WS-6 (0.17) are associated with gentle slopes, permeable soils, and high infiltration, resulting in fewer drainage channels. As noted by Langbein (1947), higher drainage density reduces water travel time due to shorter distances between streams, making it an important factor in hydrological response. The mean DD of 0.596 km/km² indicates a moderately dissected terrain with a balance between runoff and infiltration, and suggests that the drainage pattern is primarily semi-dendritic to dendritic. Overall, DD analysis provides valuable insights into terrain characteristics, flood potential, and watershed management needs.

4.2.2. Stream frequency (Fs) –

Stream frequency (Fs), defined by Horton (1932), refers to the total number of stream segments per unit area. It is an important indicator of the drainage texture and largely influenced by the underlying lithology of the watershed. In the present study, stream frequency values for sub- watersheds range from 0.08 to 0.21, with an average of 0.156 (Table 5). A positive correlation is observed between stream frequency and drainage density, suggesting that areas with higher drainage density also exhibit increased stream frequency. This pattern indicates a more dissected terrain and reduced infiltration, typical of finer drainage textures.

4.2.3. Drainage Texture ratio (T):

Horton (1945) defined drainage texture as the total number of stream segments of all orders in a basin per perimeter of the basin. It is important to geomorphology as it means the relative spacing of drainage lines. Drainage texture is controlled by the underlying lithology, infiltration capacity, and relief aspects of the terrain. Drainage texture can be classified into 5 different textures, i.e., very coarse (<2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8), and very fine (>8). In the present study, Dt values for sub-watersheds range from 0.15 to 0.41, with an average of 0.29, indicating a fine drainage texture (Table 5). This suggests that the region is characterized by moderate infiltration, soft to moderately resistant lithology, and sparse vegetation, likely influenced by semi- arid climatic conditions. The higher Dt values (e.g., 0.41 in WS-3) imply closely spaced streams and greater dissection, while lower values (e.g., 0.15 in WS-4) suggest wider spacing due to higher permeability or flatter terrain. The observed Dt patterns, when correlated with drainage density and stream frequency, reinforce the influence of both geological and climatic controls on drainage development across the sub-watersheds.

4.2.4. Form Factor (Rf):

Form Factor, introduced by Horton (1945), represents the ratio of basin area to the square of its length, indicating basin shape and flow response. In this study, Ff values range from 0.29 (WS-I) to 0.33(WS-VI), with a mean of 0.313 (Table 5), suggesting all sub-watersheds have elongated shapes. This implies longer flow paths and delayed peak runoff, reducing flash flood risk. The consistent Ff values reflect uniform terrain and slope, emphasizing the region's potential for sustainable flood and water resource management.

4.2.5. Elongation Ratio (Re):

The Elongation Ratio (Re) indicates the shape of the watershed, ranging from 0 (highly elongated) to 1 (perfectly circular). In the present study, Re values range from 0.61 (WS-I) to 0.65 (WS-II, V, VI), with a mean of 0.633 (Table 5). These values suggest that all sub-watersheds exhibit moderately elongated shapes, typically associated with moderate to high relief and steeper slopes. The relatively consistent elongation ratios reflect uniform geomorphological conditions across the study area. Watersheds with higher Re values imply a lower risk of flash floods due to extended flow paths, supporting effective planning for watershed management and soil conservation.

4.2.6. Circulatiory Ratio (Rc):

The Circulatory Ratio (Rc) reflects the shape and maturity of a basin, with values ranging from 0 (elongated) to 1 (circular). In the study area, Rc values range from 0.32 (WS-IV) to 0.57 (WS-III), with a mean of 0.47 (Table 5), indicating moderately elongated basins. These low to moderate values suggest that the sub-watersheds are structurally controlled, and in the youthful to mature **stage** of geomorphic development. Lower Rc values are influenced by irregular basin shapes, structural disturbances, and slope variations. The findings support the notion that terrain and geological conditions significantly influence drainage pattern evolution in the region.

4.2.7. Length of overland flow (Lo):

The Length of Overland Flow (Lo) is a crucial parameter indicating the average horizontal distance water travels before reaching a stream channel. As it is approximately half the inverse of drainage density (Horton, 1945), it reflects infiltration capacity and surface runoff characteristics. In the study area, Lo values range from 0.36 km (WS-V) to 3.71 km (WS-IV), with a mean of 1.6 km (Table 5). Higher values indicate gentle slopes and lower drainage densities, leading to longer runoff paths, as seen in WS-IV and WS-VI. Lower Lo values, like in WS-V, suggest steeper slopes and well-drained terrains. This variability highlights diverse topographic and hydrologic conditions across the sub-watersheds.

4.2.8. Compactness Coefficient (Cc):

The Compactness Coefficient (Cc) reflects how closely the shape of a watershed resembles a circle, which is hydrologically efficient. A lower value indicates a more compact, circular basin, resulting in quicker runoff and shorter time to peak discharge. In the present study, Cc values range from 1.32 (WS-III) to 1.75 (WS-IV), with a mean of 1.468 (Table 5). These moderate to high values suggest that most sub-watersheds are elongated rather than circular, implying longer runoff travel times and possibly delayed peak flows. The variation in compactness across watersheds indicates diverse morphometric characteristics, likely influenced by topography and structural controls.

4.3. Relief Aspects:

The relief aspects of the basin relate to the three-dimensional features and are vital for water resources studies, stream flow analysis, and denudation conditions of the watershed. The relief elements include basin relief, relief ratio, and roughness ratings, which are shown below.

4.3.1. Basin relief (R):

The basin relief (R) represents the elevation difference between the highest and lowest points within a drainage basin, indicating terrain variability and erosional potential. As per Table 5, the basin relief values across the sub-watersheds range from 80 m to 250 m, with an average of 200 m, suggesting moderate topographical variation. Watersheds V and I exhibit the highest relief (250 m and 240 m respectively), implying steeper slopes and greater runoff potential, while W.S. IV shows the lowest relief (80 m), indicating relatively flat terrain. This variation reflects diverse geomorphological conditions, influencing erosion intensity, sediment transport, and watershed hydrology in the study area.

4.3.2. Relief Ratio (Rr):

The relief ratio (Rr) reflects the overall steepness and erosional potential of a basin. As shown in Table 5, the relief ratio values in the study area range from 3.64 (W.S. IV) to 17.96 (W.S. V), with a mean value of 11.90, indicating moderate to high relief gradients. Higher values in W.S. II, V, and VI suggest steep terrain and greater runoff velocity, while lower values in W.S. IV indicate gentler slopes and reduced erosion potential. The variations are mainly determined by the nature of the underlying rock formations and the steepness of the terrain, with lower relief ratio values generally linked to harder, more resistant rocks and relatively gentle slopes.

4.3.3. *Ruggedness Number (Rn):*

The Ruggedness Number (Rn), a product of basin relief and drainage density, reflects the structural complexity and potential for erosion within a basin. In the Gopad sub-basin, Rn values range from
0.01 to 0.35, with a mean of 0.135, indicating generally low ruggedness across the watershed. Sub- watersheds IV and VI exhibit particularly low values (0.01 and 0.04), suggesting minimal structural complexity and a lower risk of severe erosion. Conversely, sub-watershed V shows a relatively higher Rn (0.35), implying steeper slopes and higher erosion potential. Overall, the low to moderate ruggedness suggests a stable terrain with limited susceptibility to intense soil degradation.

Table 4: - Stream order, Number and bifurcation cumulative stream length in different watershed

	STREAM ORDER				
Watershed (WS)	**I**	**II**	**III**	**IV**	TOTAL
	WS-I				
No. of stream	21.00	4.00	2.00	1.00	28.00
Stream length (Lu)(km)	10.65	23.68	6.81	37.08	78.22
Mean stream length(km) (Lsm)	0.51	5.92	3.40	37.08	
Stream length ratio(km) (Rl)		2.22	0.29	5.45	
Bifurcation Ratio (Rb)	5.25	2.00	2.00		

Mean Bifurcation Ratio (Rbm)			2.31		
WS-II					
No. of stream	10.00	2.00	-	1.00	13.00
Stream length (km)	5.07	11.84	-	37.08	53.99
Mean stream length(km) (Lsm)	0.51	5.92	-	37.08	
Stream length ratio(km) (Rl)		2.33	-	0.00	
Bifurcation Ratio (Rb)	5.00	-	-		
Mean Bifurcation Ratio (Rbm)			5.00		
WS-III					
No. of stream	16.00	4.00	1.00	1.00	22.00
Stream length (km)	8.11	23.68	3.40	37.08	72.28
Mean stream length(km) (Lsm)	0.51	0.00	3.40	0.00	
Stream length ratio(km) (Rl)		2.92	0.14	10.90	
Bifurcation Ratio (Rb)	0.00	4.00	0.00		
Mean Bifurcation Ratio (Rbm)			1.00		
WS-IV					
No. of stream	8.00	2.00	1.00	0.00	11.00
Stream length (km)	4.06	11.84	3.40	0.00	19.30
Mean stream length(km) (Lsm)	0.51	5.92	3.40	0.00	
Stream length ratio(km) (Rl)		2.92	0.29	0.00	
Bifurcation Ratio (Rb)	4.00	2.00	0.00		
Mean Bifurcation Ratio (Rbm)			1.50		
WS-V					
No. of stream	25.00	6.00	1.00	1.00	33.00
Stream length (km)	12.68	35.52	3.40	37.08	88.68
Mean stream length(km) (Lsm)	0.51	5.92	3.40	37.08	
Stream length ratio(km) (Rl)		2.80	0.10	10.90	
Bifurcation Ratio (Rb)	4.17	6.00	1.00	0.00	
Mean Bifurcation Ratio (Rbm)			2.79		
WS-VI					
No. of stream	8.00	-	1.00	1.00	10.00
Stream length (km)	4.06	-	4.06	3.40	11.52
Mean stream length(km) (Lsm)	0.51	-	4.06	3.40	
Stream length ratio(km) (Rl)		-	0.00	0.84	
Bifurcation Ratio (Rb)	-	-	1.00		
Mean Bifurcation Ratio (Rbm)			1.00		

Table 5: - Morphometric Analysis and Shape Parameter of different watershed

Watershed Number ⇨	W.S. I	W.S. II	W.S. III	W.S. IV	W.S. V	W.S. VI	Total	Mean
Basin Perimeter (Km)	71.45	38.89	53.08	74.74	42.82	39.82	320.8	53.46
Basin Maximum Length (Km)	24.64	13.72	20.58	21.99	13.92	14.41	109.26	18.21
Form Factor	0.29	0.33	0.30	0.30	0.33	0.33	1.88	0.313
Circulatory Ration	0.43	0.52	0.57	0.32	0.44	0.54	2.82	0.47
Elongation Ration	0.61	0.65	0.62	0.62	0.65	0.65	3.8	0.633

Drainage Texture (Dt)	0.39	0.33	0.41	0.15	0.26	0.25	1.79	0.29
Compactness Coefficient	1.51	1.38	1.32	1.75	1.50	1.35	8.81	1.468
Drainage Intesity (Id)	0.36	0.24	0.30	0.57	0.12	0.87	2.46	0.41
Total Number of Stream	28.00	13.00	22.00	11.00	33.00	10.00	117	19.5
Stream Frequency	0.16	0.21	0.17	0.08	0.17	0.15	0.94	0.156
Drainage Density	0.45	0.87	0.57	0.13	1.39	0.17	3.58	0.596
Infiltration Number	0.07	0.18	0.10	0.01	0.24	0.02	0.62	0.103
Constant of Channel maintenance (C)	2.23	1.15	1.76	7.41	0.72	5.90	19.17	3.195
Length of Overland flow	1.12	0.58	0.88	3.71	0.36	2.95	9.6	1.6
Basin Relief (m)	240	210	210	80	250	210	1200	200
Relief ratio (Rr)	9.74	15.30	10.20	3.64	17.96	14.57	71.41	11.90
Ruggedness Number	0.11	0.18	0.12	0.01	0.35	0.04	0.81	0.135
Mean Bifurcation Ratio (Rbm)	2.31	5	1	1.5	2.79	1	13.6	2.26

V. CONCLUSION

The geomorphic analysis of the six sub-watersheds (WS I, WS II, WS III, WS IV, WS V, WS VI) provides significant insights into their hydrological and structural characteristics. The study reveals that the highest stream frequency is observed in first-order streams, with a decreasing trend as stream order increases. The bifurcation ratio (Rb) ranges from 1 to 5, with a mean value of 2.26, indicating variations in structural influence across the watersheds. High Rb values suggest structural control on the drainage pattern, whereas lower values indicate minimal structural disturbances. The drainage density (Dd) varies from 0.13 to 0.87, reflecting differences in infiltration and runoff characteristics. Sub-watersheds II and IV, which have comparatively lower Dd values, are identified as suitable locations for artificial recharge due to higher infiltration potential. The drainage texture (Dt) values range from 0.15 to 0.41, with a mean of 0.3, indicating a fine drainage texture. Morphometric parameters such as the circularity ratio (Rc), form factor (Ff), and elongation ratio (Re) further support the classification of watersheds in terms of shape, relief, and hydrological behavior. The Rc values (0.32–0.54) suggest that most tributaries are in a mature stage of development. The Ff values (0.29–0.33) indicate variations in basin shape, where higher values represent more circular basins. The Re values (0.61–0.65) suggest low to moderate relief and diverse climatic and geological features. The infiltration number (If) of 0.10 highlights low runoff conditions in the study area, further supporting groundwater recharge potential. Relief analysis indicates that sub-watershed V has the highest relief, while sub-watershed IV has the lowest. High-relief watersheds (WS I, II, III, V, and VI) exhibit lower infiltration, whereas low- relief watersheds (WS IV) favor higher infiltration, making them ideal for artificial groundwater recharge. Overall, the study provides valuable information for watershed management, particularly in identifying areas suitable for artificial recharge. Sub-watershed IV emerges as the most favorable region for groundwater recharge due to its low relief, low drainage density, and high infiltration capacity. These findings can aid in sustainable water resource planning, ensuring efficient groundwater management in the study area.

REFERENCES

[1]. Adhikari, S.(2020) Morphometric Analysis of a Drainage Basin: A study of Ghatganga River, Bajhang District, Nepal. The Geographic Base. Vol.7: 127-144. DOI: 10.3126/tgb.v7i0.34280

[2]. Dwivedi, A.P., Tripathi, I.P. & Kumar, M Suresh. (2013). Assessment of soil and groundwater quality in Rewa district of Vindhyan Plateau (India). Journal of environmental science& engineering. 55(1). 51-64.

[3]. Karanth, K.R. (1989). Groundwater assessment, development and management. Tata McGraw-hill Publ. Com. Ltd., New Delhi.

[4]. Kumar, C. P. (2018). Water Resources Issues and Management in India. The Journal of Scientific and Engineering Research, 5(9):137-147. ISSN: 2394-2630.

[5]. Mishra, A., Dubey, D.P., & Tiwari R. N. (2011) Morphometric analysis of Tons basin, Rewa District Madhya Pradesh, based on watershed approach. Earth Science India. 4(3).171-180. eISSN: 0974-8350

[6]. Pande, C., Moharir, K., and Pande, R. (2021). Assessment of morphometric and hypsometric studies for watershed development using spatial technology–a case study of the Wardha river basin in Maharashtra, India. International Journal of River Basin Management, 19(1), pp. 43-53.

[7]. Patel, A., Ajaykumar, K., Dhaloiya, A., Rao, K.V., Rajwade, Y., &Saxena, C. (2023). Application of Remote Sensing and GIS for Morphometric Analysis: A Case Study of Burhanpur Watershed. Surface and Groundwater Resources Development and Management in Semi-arid Region (pp.21–37) DOI: 10.1007/978-3-031-29394-8_2

[8]. Prakash, K., Chaubey, K., Singh, S., Mohanty, T., & Singh, C.K. (2017). Morphometric analysis of the Satna River

Basin, Central India. Indian Journal of Geomorphology, 22(1):41-60. ISSN: 2454- 3616.
[9]. Rajasekhar, M., Raju, G.S., and Raju, R.S., (2020). Morphometric analysis of the Jilledubanderu river basin, Anantapur District, Andhra Pradesh, India, using geospatial technologies. Groundwater for Sustainable Development, 11, p. 100434.
[10]. Saha, A., and Singh, P. (2017). Drainage morphometric analysis and water resource management of the Hindon river basin using earth observation data sets. International Journal of Interdisciplinary Research (IJIR), 3(4), pp. 2051-2057.
[11]. Shukla, S., and Gedam, S. (2019). Evaluating Hydrological Responses to Urbanization in a Tropical River Basin: A Water Resources Management Perspective. Nat Resour Res 28, 327–347 https://doi.org/10.1007/s11053-018-9390-7
[12]. Singh, P., Gupta, A., and Singh, M. (2014). Hydrological inferences from watershed analysis for water resource management using remote sensing and GIS techniques. The Egyptian Journal of Remote Sensing and Space Science, 17(2), pp. 111-121.
[13]. Singh, R.B., Rathore, N., Mishra, P., Singh, U., Pysai, S.K., and Dubey, A. (2019). Rainfall variability analysis of Rewa district in Madhya Pradesh. Bull. Env. Pharmacol. Life Sci, 8, pp. 74-77.
[14]. Singh, V. & Dubey, A. (2012). Linear aspects of Naina-Gorma river basin Morphometry, Rewa district, Madhya Pradesh, India. International Journal of Geometics and Geosciences. 3(2). ISSN: 0976-4380.
[15]. Singh, Yamuna, and Dubey, D.P. (2014). Hydrogeology of the Rewa Region, Central India. Watershed Management for Sustainable Development, Excellent Publishers, New Delhi, pp. 122-134.
[16]. Surinaidu, L., Rao, V.G., and Ramesh, G. (2013). Assessment of groundwater inflows into Kuteshwar Limestone Mines through a flow modelling study, Madhya Pradesh, India. Arabian Journal of Geosciences, 6, pp. 1153-1161.
[17]. Talati, J. and Kumar, M.D., (2019). From watershed to sub-basins: Analyzing the scale effects of watershed development in Narmada River basin, central India. In Current Directions in Water Scarcity Research (Vol. 1, pp. 87-101). Elsevier.
[18]. Tiwari, R.K., Tripathi, S.K., and Khan, I.M. et al. (2014). Management Techniques of Water and Nutrients for Rice Production. Watershed Management for Sustainable Development, Excellent Publishers, New Delhi, pp. 92-96.
[19]. Tiwari, R.N., and Kushwaha, V.K. (2021). Watershed Prioritization Based on Morphometric Parameters and PCA Technique: A Case Study of Deonar River Sub-basin, Sidhi Area, Madhya Pradesh, India. J Geol Soc India 97, 396–404 https://doi.org/10.1007/s12594-021-1697-z
[20]. Tiwari, R.N., and Mishra, U., (2011). Morphometric Analysis of Sirmour Area, Rewa District, Madhya Pradesh, Using Remote Sensing and GIS. International Journal of Arts, Sciences, and Engineering, 4(3), pp. 512–521.
[21]. Tiwari, Rabindra N., and Singh, Shrutika (2016). Assessment and Management of Groundwater Resources Around Govindgarh Area, Rewa District, Central India. Recent Advancements in Mineral and Water Resources, Excellent Publishers, New Delhi, pp. 142-146.
[22]. Tiwari, Sars, Mishra, U.K., Tripathi, A.K., et al. (2016). Hydrogeological Study of Ken River Basin, Central India. Recent Advancements in Mineral and Water Resources, Excellent Publishers, New Delhi, pp 162-166.
[23]. Tripathi, A.K. et.al. (2020). Assessment and Management of Groundwater Resources of Gohparu Area, Shahdol District, Madhya Pradesh, India; Shodh Chetana, G.H. Publication Prayagraj, Vol.4, PP 132-136.
[24]. Tripathi, Shashikant, Sengupta, H.P. and Tripathi, Shashank (2014). Village-Level Watershed-Based Water Security Plan Using Geopatial Technology: A Case Study of Gore Mau Kalamn of Naraini Block of Banda District, U.P. Watershed Management for sustainable Development, Excellent Publishers New Delhi, pp 97-109.
[25]. Yadav, N., Kumar, Dr A., Pani, S. & Sharma, M. (2014). Water Quality Assessment of Chambal River in National Chambal Sanctuary of Madhya Pradesh. Environmental Sustainability: Concepts, Principles, Evidences and Innovations. Pp 24-35, ISBN: 978-93-83083-75-6.