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MORPHOMETRIC ANALYSIS OF GOUR RIVER CATCHMENT: A GIS BASED APPROACH

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ABSTRACT

Geographical information system based approach proved to be an efficient tool in the delineation, updating and morphometric analysis of watershed. In present study morphometric analysis has been carried out for two watersheds of Gour river catchment falling in Jabalpur district of Madhya Pradesh, India. The morphometric parameters of the watersheds are classified under linear, areal and relief aspects. The drainage pattern shows dendritic pattern indicating homogeneity of underlain material, while about the geological structure, not disturbing the drainage pattern is indicated by the value of bifurcation ratio. Shape parameter i.e. form factor of watersheds suggests that the watersheds are more or less moving towards elongated shape from the oval shape. Circulatory ratio values of watersheds fall within the range of elongated basin and low discharge. The area has low drainage density indicating the region has high permeable subsoil material.

Key words: Morphometry, Catchment, Remote sensing, GIS

1. INTRODUCTION

Wearing away of soil and its depostion in streams that are connected to a net work forms a fluvial landforms. [1] first introduced the morphometric studies on river basins, and this idea was later developed by [2] and [3]. In India, some of the studies on morphometric analysis using remote sensing techniques were carried out by [4], [5] and [6]. More recently, [7] have carried out morphometric analysis of sub-watersheds in Gurdaspur district, Punjab, [8] in Uttala River watershed of Son River basin in Madhya Pradesh and [9] taken up morphometric study in Barchha nala watershed of Narmada River basin situated in Narsinghpur district of Madhya Pradesh.The morphometric analysis of a drainage basin and channel network play a significant role in understanding the hydrological behavior of watershed and expresses the prevailing climate, geology, geomorphology, and structure, etc.

Watershed is a hydrological unit from which all precipitated water flows to a common outlet [10]. In other words, the watershed is a dynamic geographical unit, which covers all land that contributes runoff to a common outlet [11]. Hence, a watershed becomes an ideal unit for management of natural resources i.e. land, water, forest, soil, etc. Topography, stream network, soil, vegetation and geomorphology of any area are some of the critical parameters which play a significant role in watershed planning. Watershed management involves proper utilization of natural resource of a watershed for excellent production with minimum hazard to natural resources [12].

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Drainage analysis based on morphometric parameters is paramount for watershed planning since it gives an idea about the basin characteristics regarding slope, soil condition, runoff characteristics, surface water potential, etc. The development of land form and drainage network depends on the bedrock lithology and associated geological structures. Hence, information on geomorphology, hydrology, geology and land cover can be obtainedby studying reliable information of the drainage pattern and texture [13].Thus, growth of drainage network by the prevailing lithology and geologic structures can be well understood by examining the type of the drainage pattern and by a quantitative morphometric analysis [14]. The morphometric analysis of any catchment and its drainage system can be better achieved through measurement of linear,areal and reliefa spects of drainage network. The morphometric analysis could be used for prioritization of sub-watersheds by computing linear and shape parameters [12].

Advancement of remote sensing and geographical information system opened a new path in morphometric analysis. GIS is a usefultool to analyze spatial, non-spatial data on drainage, geology and landform parameters to understand their interrelationship. Morphological analysis is a ways or means of quantifying mathematically to different aspects of a drainage basin, which includes, stream numbers, stream length,stream bifurcation, basin shape, drainage density, basin relief, basin height, basinarea, etc. Drainage characteristics of basin and sub-basin have been studied using conventional methods ([15], [16], [3]). Morphometric analysis using remote sensing and GIS have been well attempted by number of researchers ([6], [17], [5], [18], [19], [20]) and all have arrived at the conclusion that remote sensing and GIS are powerful tools for examainng basin morphometry.In the present study, efforts were made to explore the drainage characteristics of two watersheds of Gour River basin i.e. Khurjinala and Dala Nala watershed situated in Jabalpur district of Madhya Pradesh, India.

2. Materials and methods

The present study is carried out in two watersheds namely Khurji Nala and Dala Nala watersheds which are tributaries of Gour River located in Jabalpur district of Madhya Pradesh. Both the watersheds are situated between 79°58'6.72" and 80°4'59.10" E longitude and 23°1'46.15" and 23°6'25.03" N latitude with an elevation range from 400 m to 560 m above MSL (mean sea level). The drainage area of Khurjinala and Dala nala watersheds are 20.07 km^2 and 42.71 km^2 respectively. The location map of the study area is shown in Fig 1. The average annual rainfall is 1150 mm, which is concentrated mostly between mid-June to mid-September with widespread winter rains during late December and January months.

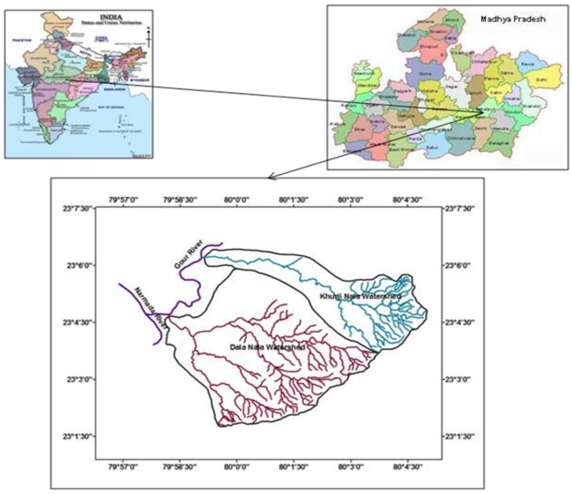

Fig 1 Location map of Study area

Survey of India (SOI) toposheets numbered 55 M/16 and 64 A/4 on 1:50000 scales were used for the topological information of the area, using the capabilities of ArcInfo and ArcGIS tools. The drainage network and contours were digitized (Fig 2) to generate the line feature class in ArcGIS which were used to delineate the watershed and sub-watersheds (Fig 3). The input parameters for a present study such as area, perimeter, stream order, stream number, length of stream, length of basin and elveation were determined from digital drainage network and contour map in GIS environment. The geomorphic parameters for the delineated watershed are calculated using standered formula recommended by [15], [3], [21] and [16] given in Table 1.

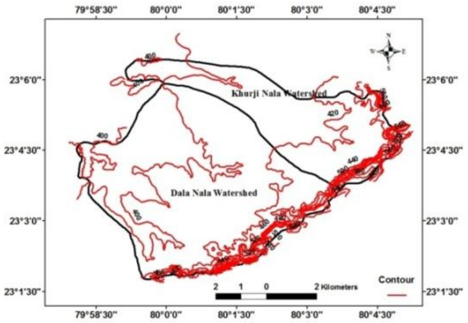

Fig 2 Contour map of Study area

Table 1:Formula for computation of Geomorphic parameters

Geomorphic Parameters	Formula	Reference
Bifurcation Ratio (R_b)	$R_b = N_u / N_{u+1}$ Where, Rb = Bifurcation Ratio N_u = Total number of stream of segment of order u N_{u+1} = Total number of stream of segment of next higher order	[21]
Drainage density (D_d)	$D_d = L_u / A$ Where, Dd = Drainage density L_u = Total stream length of order u A = Area of watershed	[15]
Stream Frequency (F_u)	$Fu = N_u / A$ Where, N_u = Total number of streams of all order A = Area of watershed	[15]
Circulatory ratio (R_c)	$Rc = 4 \Pi A / P^2$ Where, R_c = Circulatory ratio A = Area of watershed P = Perimeter	[16]
Form factor (R_f)	$R_f = A / L_b^2$ Where, Rf = Form factor A = Area of watershed L_b = Length of watershed	[15]
Elongation ratio (R_e)	$Re = (2/L_b) * (A/ \Pi)^{0.5}$ Where, R_e = Form factor A = Area of basin L_b = Length of basin	[21]
Relative relief (R_r)	$R_r = H/P$ Where, R_r =Relative relief H=Maximum watershed relief P= Perimeter of basin	
Relief ratio (R_h)	$R_h = H / L_b$ Where, R_h= Relief ratio H=Maximum watershed relief L_b = Length of basin	
Ruggedness number (R_N)	$R_N = H * D_d$ Where, R_N= Ruggedness number H=Maximum watershed relief D_d = Drainage density	
Texture ratio (T)	T = N / P Where, T = Texture ratio N = Total number of streams of all order P = Perimeter (km)	[15]
Compactness coefficient (C_c)	$C_c = 0.2821 P/A^{0.5}$ Where, C_c= Compactness coefficient	[15]

	P = Perimeter (km) A = Area of basin	
Length of over land flow	$L_o = 1/2\ D_d$ Where, L_o = Length of Over land flow D_d =Drainage density	

3. RESULT AND DISCUSSION

Sub-watershed wise morphometric parameters of Khurji Nala and Dala nala watersheds were derived in GIS environment and are presented in Table 2 & 3 and computed geomorphometric parameters are listed in Table 4& 5 respectively

Table 2 Sub-watersheds wise input parameters derived in GIS environment of Khurji nala watershed

Subwatershed No.	Area Km^2)	Perimeter (Km^2)	Max. elevation (m)	Min. elevation (m)	Total relief (m)	No. of stream	Max. length of watershed (km)	Total stream length (km)
1	1.08	4.70	564	418	146	10	1.99	6.08
2	1.95	6.32	450	395	55	9	2.43	7.07
3	3.24	8.06	565	414	151	27	2.39	18.08
4	1.88	7.04	570	412	158	11	2.71	8.00
5	11.84	23.35	565	396	169	7	9.13	17.25

Table 3 Sub-watersheds wise input parameters derived in GIS environment of Dala nala watershed

Subwatershed no.	Area (km^2)	Perimeter (km)	Max. elevation (m)	Min. elevation(m)	Total relief(m)	No. of stream	Max. length of watershed (km)	Total stream length(km)
1	3.85	8.72	565	396	169	18	3.27	27.65
2	1.46	4.88	472	396	76	8	1.84	11.04
3	8.03	15.61	564	398	166	34	5.57	57.97
4	4.30	10.23	443	397	46	8	4.53	16.90
5	3.38	9.26	564	394	170	14	3.72	23.65
6	1.78	5.94	490	395	95	9	2.04	12.48
7	19.88	27.62	425	396	29	17	7.29	51.34

The maximum length of sub-watersheds of Khurjinala and Dala nala watersheds is presented in Table 2 and 3 respectively. Sub-watershed 5 has a largest maximum length of watershed i.e. 9.13 km while sub-watershed 1 has the minimum value i.e. 1.99 km among all five sub-watersheds of Khurjinala watershed. In Dala nala watershed, sub-watershed 7 has al argest maximum length of watershed i.e. 7.29 km, whereas, sub-watershed 2 has the minimum value i.e., 1.83 km.

Table 4 Sub watershed-wise computed morphometric parameters of Khurji nala watershed

Sws no.	R_b	R_f	R_e	R_c	D_d	F_u	R_h	R_N	R_r	T	C_c	L_o
1	2.753	0.273	0.590	0.617	5.610	9.221	0.073	0.819	0.031	2.127	1.273	2.805
2	2.501	0.329	0.647	0.613	3.626	4.613	0.023	0.199	0.009	1.422	1.278	1.813
3	3.001	0.565	0.848	0.626	5.579	8.328	0.063	0.842	0.019	3.347	1.264	2.790
4	2.662	0.257	0.572	0.478	4.240	5.829	0.058	0.670	0.022	1.562	1.446	2.120
5	2.902	0.142	0.425	0.273	1.457	0.591	0.019	0.246	0.007	0.300	1.914	0.729

Table 5 Sub watershed-wise computed morphometric parameters of Dala nala watershed

Sws no.	R_b	R_f	R_e	R_c	D_d	F_u	R_h	R_N	R_r	T	C_c	L_o
1	3.625	0.360	0.677	0.635	3.591	4.674	0.052	0.607	0.019	2.062	1.255	1.796
2	2.250	0.435	0.745	0.772	3.772	5.672	0.041	0.287	0.016	1.639	1.138	1.886
3	5.250	0.259	0.574	0.414	3.545	4.231	0.030	0.589	0.011	2.177	1.554	1.773
4	2.250	0.209	0.516	0.516	1.965	1.859	0.010	0.090	0.004	0.782	1.391	0.982
5	3.750	0.243	0.557	0.495	3.501	4.141	0.046	0.595	0.018	1.511	1.421	1.751
6	2.500	0.429	0.739	0.637	3.478	5.031	0.047	0.330	0.016	1.515	1.253	1.739
7	1.389	0.373	0.690	0.327	1.338	0.855	0.004	0.039	0.002	0.615	1.748	0.669

Stream Order

The stream order is a measure of the position of a stream in the hierarchy of the tributaries [15]. [3] advanced slightly different method and according to him the smallest finger trip and unbranched (which have no tributary) stream segment have designated as first order stream. The second order streams are those which have only first order streams as tributaries. Similarly, the third order stream receives first and second streams as tributaries, and so forth. The trunk or principles stream through which all the discharge and sediments passesis, therefore, the stream segment of the highest order.

After analysis of drainage map, it was found that the Khurji nala watershed is of 4^{th} order type and Dala nala watershed is of 5^{th} order type. The total number of streams in Khurji nala 67 and 108 in Dala nala watersheds were identified of which 48 are of 1^{st} order in Khurji nala and 78 in Dala nala, 13 are of 2^{nd} order in Khurji nala and 21 in Dala nala, 5 are of 3^{rd} order in Khurji nala and 6 in Dala nala, 1 is of 4^{th} order in Khurji nala and 2 in Dala nala and one is of 5^{th} order stream in Dala nala watershed. The drainage pattern of streams network from both the watersheds has been observed as the mainly dendritic type which indicates homogeneity in texture and lack of structural control. The properties of the stream network are very important to study the landform making process. The order wise total number of streams segment is known as stream number. Laws of stream states that the number of stream segments of each order forms an inverse geometric sequence with plotted against the order, most drainage networks show a linear relationship, with small deviation from linearity.

Bifurcation ratio (R_b)

The term bifurcation ratio (R_b) is a ratio of the number of streams of any given order to the number of streams in next higher order [21]. Bifurcation ratio characteristically ranges between 3.0 and 5.0 for basins in which drainage pattern is not affected by geological structures [3]. [3] demonstrated that bifurcation ratio shows a small range of variation for different regions or different environment dominates. The mean bifurcation ratio value is 2.7 for Khurjinala and 3.1 for Dala nala watershed falls near to standard range and shows that both the watershed confirms to the characteristics of a natural stream which indicated that the geological structures are less disturbing to the drainage pattern.

Form factor (R_f)

[1] suggested, form factor ratio, which is the dimensionless ratio of basin area to the square of basin length. Basin shape may be indexed by simple dimensionless ratios of the core measurement of area, perimeter, and length [22].The sub watershed 3 has a maximum value (R_f = 0.565) while sub-watershed 5 has a minimum value (R_f = 0.142) in Khurjinala watershed. The small value of form factor indicates the elongated shape of sub-watershed. Thus in sub-watershed 3 of Khurjinalawatershed, there will be higher peak flow, whereasin sub-watershed 5it will be the flatter peak. Similarly, in Dala nala watershed, form factor varies from 0.209 for Subwatershed 4 and 0.435 for subwatershed 2. So, in this case, there is a flat peak in sub-watershed 4 and a higher peak in sub-

watershed 2 respectively. The elongated basin with form factor indicates that the sub-watershedswill have flatter peaks for a longer duration. Flood flows of such elongated sub-watersheds are easier to manage than that of the circular watershed [4].

Elongation ratio (R_e)

[21] defined elongation ratio as the ratio of the diameter of a circle of the same area as the basin to the maximum basin length. It is an important parameter in the analysis of shape of basin which helps to understand the hydrological behavior of a drainage basin.The value of elongation ratio ranges from 0.6 to 1.0 over a wide variety of climate and geologic type [21]. The value close to 1.0 is typical of regions of very low relief, whereas values in the range 0.6 to 0.8 are associated with high relief and steep slope [3] and [23]. These values can be grouped into four categories namely Circular (above 0.9), Oval (0.8 - 0.9), Less elongated (0.7 - 0.8), Elongated (below 0.7).

The subwatershed 3 has a maximum value (R_e = 0.848) while sub-watershed 5 has a minimum value of R_e (R_e = 0.425) in Khurji nala watershed and in Dala nala watershed the subwatershed 2 has a maximum value (R_e = 0.745) while sub-watershed 4 has a minimum value of R_e (R_e = 0.516).

It is observed that the smaller the fraction, the more elongated is the shape of the basin, and higher the elevation, the more circular is the shape of the basin [24] and [25]. It is evident from the preceding discussion that the elongation ratio is a paramount index in the analysis of basin shape, which provides an idea of the hydrological character of the drainage basin. This information is critical, particularly in the flood forecasting.

Circulatory ratio (R_c)

[16] introduced the circulatory ratio to quantify the basin shape. The ratio is equal to unity when the basin shape is a perfect circle, decreasing to 0.785 in the case of square shape and continuous to reduce to the extent which the basin becomes elongated [23]. The subwatershed 3 has a maximum value (R_c = 0.626) while sub-watershed 5 has a minimum value (R_c =0.273) observed in Khurjinala watershed and while studying the Dala nala watershed, the sub-watershed 2 has a maximum value (R_c = 0.772) while sub-watershed 7 has a minimum value (R_c =0.327).

Drainage density (D_d)

D_d is the indicator of drainage efficiency of the watershed. Langbein (1947) recognized the significance of D_d as a factor determining the time of travel by water within the basin. The lowest and highest values of D_d are found to be 1.457 and 5.610 for subwatershed 5 and sub-watershed 1 of Khurjinala watershed and 1.338 and 3.772 for subwatershed 7 and sub-watershed 2 of Dala nala watershed respectively. High drainage density revealed the well-defined channel network and would produce more runoff and cause serious erosion problem in the area [24].

Low D_d values for sub watershed 5 and sub-watershed 7 of Khurjinala and Dala nala watersheds indicates that it has the region underlain by highly permeable subsoil material with densely vegetated cover, with high values of D_d have a well-developed network and torrential run-off resulting in an intense flood. Also, high D_d value for subwatershed 3 and 2 of Khurjinala and Dala nala watersheds indicates a situation conducive for quick disposal of run-off and characterized by a region of weak subsurface materials. Similar is the case for Dala nala watershed. Thus, the study of various factors which control drainage density such as lithology, compactness of the surface, vegetative covers, relief, etc. for the study area shows that the results are consistent with D_d measurements made in similar terrain.

Stream frequency (F_u)

The subwatershed 1 has maximum (F_u = 9.221), while sub-watershed 5 has minimum F_u (F_u = 0.591) in Khurjinala watershed while in Dala nala watershed, the sub-watershed 2 has maximum (F_u =5.672), while sub-watershed 7 has minimum F_u (F_u = 0.855). The stream frequency relates to permeability, infiltration capability and relief of watershed. Values of streamfrequency of sub-watershed area exhibit positive correlation with drainage density values of the area indicating the increase in drains population on drainage density.

Relief ratio (R_h)

Relief ratio is a measure of potential energy available to move water and sediment down the slope. Reliefratio value ranges from 0.007 to 0.031 for sub watershed5 and 1 respectively in Khurjinala watershed and in Dala nala watershed, sub watershed7 and 1 has the maximum and minimum value of relief ratio with 0.002 and 0.019. Relief has no effect on both the watershed.

Ruggedness number (R_N)

The sub watershed 3 has maximum (R_N=0.842), and 2 has minimum ruggedness number (R_N=0.199) while sub-watershed 1 and 7 has the maximum and minimum value of R_N (R_N = 0.607 and 0.039) 0f Khurjinala and Dala nala watersheds respectively. The high value of roughness number indicates the structural complexity of the terrain in association with relief and drainage density. It also implies that the area is susceptible to more soil erosion.

Relative relief (R_r)

Relative relief values of Khurji nala of sub-watershed 1 (R_r = 0.031), while sub-watershed 5 has (R_r = 0.007) and whereas in Dala nala watershed sub-watershed 1 has (Rr =0.019) and sub-watershed 7 has a value of R_r (0.002). The overall relative relief shows very low relief in both the watersheds.

Texture Ratio (T)

Texture Ratio is an important factor in drainage morphometric analysis which depends on the underlying lithology, infiltration capacity and relief aspect of the terrain. Values of Texture Ratio Khurji nala watershed varies from 0.3 (sub-watershed 5) to 3.347 (sub-watershed 3), whereas of Dala nala from 0.615 (sub-watershed 7) to 2.177 (sub-watershed 3).

Compactness Coefficient (C_c)

Compactness coefficient of Khurji nala watershed ranges from 1.278 (sub-watershed 2) to 1.914 (sub-watershed 5) and in case of Dala nala watershed it ranges between 1.253 (sub-watershed 6) and 1.748 (sub-watershed 7).

Length of Overland Flow (L_o)

This parameter refers to the length of the run of the rain water on the ground surface before it gets localized into the definite channel. The length of overland flow is considered as dominant hydrologic and morphometric factor and is the mean horizontal length of flow path from the water divide to the stream in a first order basin and is measure of stream spacing and degree of dissection. In Khurji nala watershed sub-watershed 1 has maximum (L_o= 2.805 km) and sub-watershed 5 has minimum (L_o= 0.729 km), whereas in case of Dala nala watershed sub-watershed 2 has maximum (L_o= 1.886 km) and sub-watershed 7 has minimum (L_o= 0.669 km) length of over land flow.

4. CONCLUSION

Morphometric analysis is found to be very useful for management of natural resourecs as it gives the better idea about the hydrological behavior of watershed through this quantitive analysis. The morphometric analysis carried out in two watersheds i.e. Khurji nala and Dala watershed of Gour River shows that the watersheds are having low relief of the terrain and is oval tending towards elongated shape. Drainage network of the watersheds exhibits dendritic type which indicates the homogeneity in texture and lack of structural control. The morphometric parameters evaluated using GIS helped us to know the various basin charactristics such as bedrock material underlain, infiltration capacity, surface runoff etc.

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