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Gour River Sub-watersheds Prioritization using Morphometric Parameters: A Remote Sensing and GIS Based Approach

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Abstract— **For natural resources management at present time, watershed prioritization has gained importance, especially in the context of planning and management of watersheds. Usually morphometric analysis is useful for prioritization of watersheds. Presents study makes an effort to prioritize two sub-watersheds i.e. Khurji nala and Dala nala watershed of Gour River, based on morphometric analysis using remote sensing and GIS techniques located in Jabalpur district of Madhya Pradesh. Various morphometric parameters, namely bifurcation ratio (R_b), form factor (R_f), elongation ratio (R_e), circulatory ratio (R_c), drainage density (D_d), drainage frequency (D_f), relief ratio (R_h), and ruggedness number (R_N) for each sub-watershed has been estimated using standard formulae and ranks were assigned to arrive at final ranking of the sub-watersheds for prioritization. Sub-watershed 1 of Khurji nala and sub-watershed 1 and 5 of Dala nala are on top priority based on the morphometric analysis, so soil and water conservation measures should be started from these sub-watersheds**

Index Terms—**Morphometry, Remote Sensing, Geographical Information System, Watershed**

I. Introduction

Availability of natural resources is decreasing over the years due to ever increasing population pressure. Infrastructural facilities are to be developed for industrial expansion which is very much needed in present time and as a result of that further pressure comes on limited land and water resources. In India about 172 m ha of land suffers from serious soil erosion and other froms of land degradation. A country like India that supports 16 per cent of world population on 2 per cent global land area, shows severity of the problem [7]. So, planning, management and development of land and water resources on sustainable basis is very important. For their efficient and sustainable management one has to look for sustainable unit so that these resources can be handled and managed effectively. The watersheds or hydrological units are considered more efficient and appropriate for necessary survey and investigation for the assessment of these resources and subsequent planning and implementation of various development programmes like erosion control in river basins along with conservation of water, dry land/rainfed farming, reclamation of ravine lands etc. A hydrological unit i.e. watershed is an area from which all precipitated water flows to a single outlet [8].The hydrologic units are equally important for the development of water resources through major, medium and minor storage projects as well as farm level water storage structures. Therefore, watershed approach is more useful to best utilize these natural resources.

It is very important to understand the hydrological behavior of that watershed for its effective management. To understand the hydrological behavior of any watershed, it requires immense data on hydrological parameters. In most of the developing countries including India, lacks in the gauging of small watersheds for hydrological parameters. So, the morphometric analysis of watershed can play an important role in inadequate data situation. The morphometric characteristic of a watershed represents its attributes and can be helpful in synthesizing its hydrological behavior [6]. It is very difficult to develop the large area in one stretch due to some geo-environmental or financial situations. So, before implementing any developmental program there is a need to prioritize watersheds. Advancement of remote sensing and geographical information system opened a new path in morphometric analysis and there by prioritization of watersheds. GIS is a useful tool 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, basin area, etc.

[5] carried out check dam positioning by prioritization of micro-watersheds using Sediment Yield Index (SYI).[2] in sub-watersheds of Dikrong river basin of Eastern Himalayas and identified the sub-watersheds which are more prone to erosion using morphometric parameters and F factor approach. Prioritization of sub-watersheds based on morphometric analysis of drainage basin using remote sensing and GIS techniques was attempted by [10] in sub-watersheds of Sharpha river located in Sahadol district of Madhya Pradesh. [9] in their one of the attempt prioritized the sub-watersheds of Barchha nala watershed situated in Narsinghpur district, Madhya Pradesh, based on morphometric analysis using RS and GIS approach.

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This study is aimed at studying the geomorphological characteristics of study sub-watersheds and also finding out the sub-watersheds which are more susceptible to erosion with the morphometric analysis approach. In the present study morphometric analysis and prioritization of sub watersheds are carried out for two sub-watersheds of Gour river basin located in Jabalpur district of Madhya Pradesh for further developmental planning.

II. MATERIALS AND METHODS

A. *Study area*

The present study is carried out in two watersheds i.e. Khurji Nala and Dala Nala watersheds of Gour river basin situated in Jabalpur district of Madhya Pradesh. Both the watersheds are positioned 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). Drainage area of Khurji nala 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.

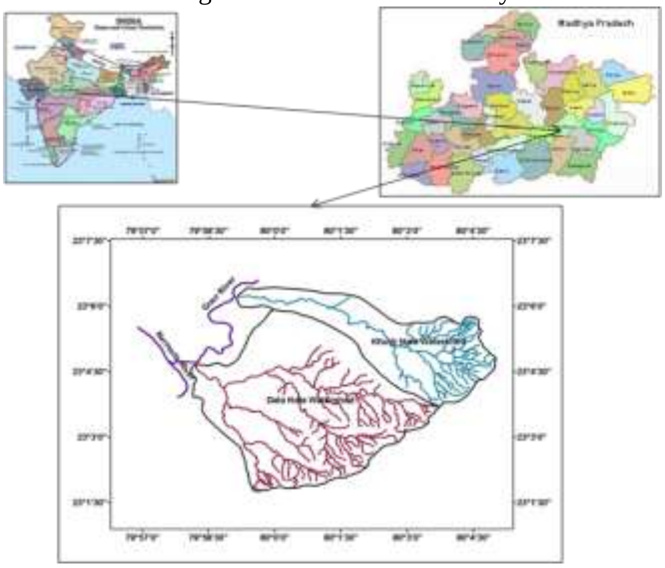

Fig 1 Location map of study area

Base Map of the study area is prepared using Survey of India (SOI) toposheet 55M/16 and 64A/4 on 1:50000 scale. These toposheets were imported in EDRAS imagine 9.1 software. Subsequently toposheets were georeferenced using (Projection and Coordinate System) conic (Geographic Coordinate System) GCS_Indian 1975. Georefrenced toposheets were mosaiced to have final base map. Further processing was done in Arc-GIS. Satellite data of IRS P6 row & path 100/56 acquired from National Remote Sensing Agency (NRSA) for 13th January 2011 used in this study to prepare updated drainage layer. Fig 2 and 3 presents FCC (False Colour Composite) and drainage map respectively. Contour map is shown in Fig 4.

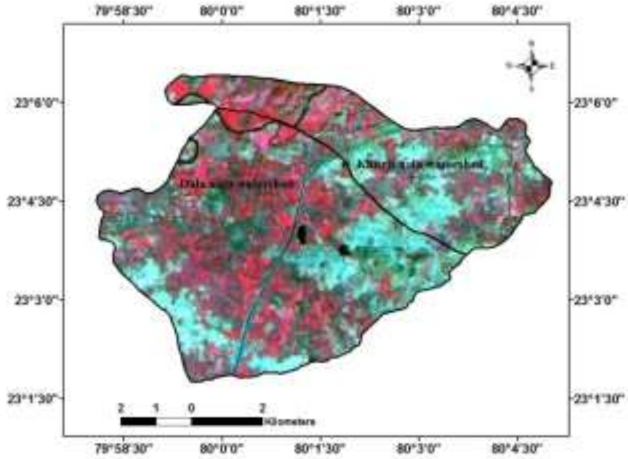

Fig 2 FCC of study area

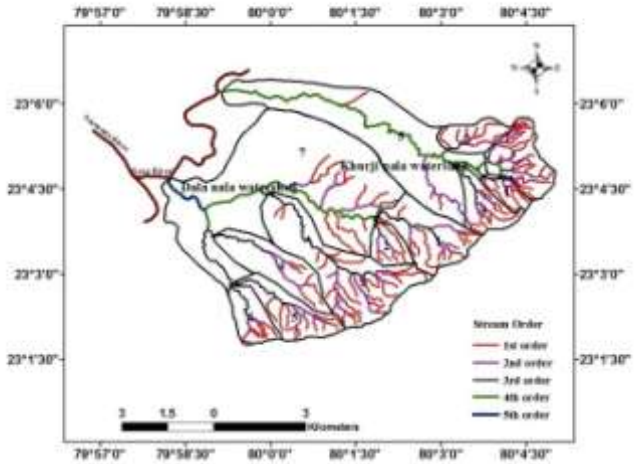

Fig 3 Drainage map with sub-watershed boundry

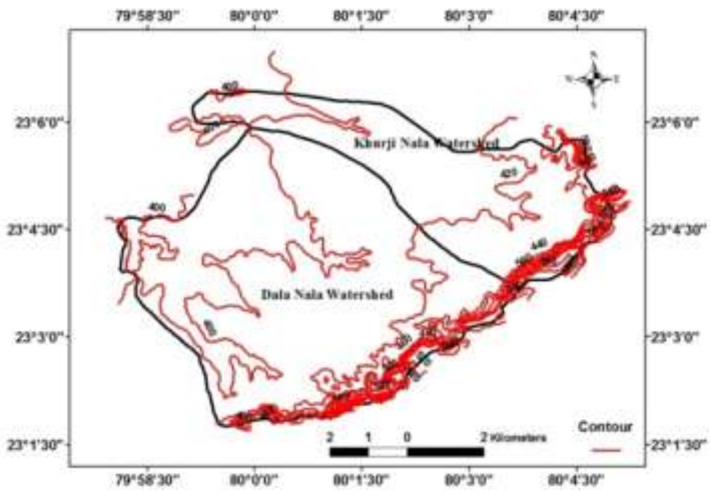

Fig 4 Contour map of study area

B. *Morphometric analysis*

Quantitative analysis is very advantageous as the basins parameters estimated are in the form of dimensionless values, provides an efficient assessment regardless of scale.

Stream order Stream ordering is the first step in morphometric analysis, so for designation of stream, [11] approach was used in this study. First order streams are those which initiates from the source. Second order streams will be created when two first order streams joins each other. Highest order of the stream will show the order of the basin.

Stream Number (N_u) It is the number of stream sections of different order and is inversely proportional to the stream order.

Total Stream Length (L_a) It is the length of all the streams having order u. It indicates the contributing area of the basin of that order.

Watershed Perimeter (P_r) It is the length of the watershed boundary.

Maximum Length of Watershed (L_b) It is the distance between watershed outlet and most remote point of the watershed.

Bifurcation ratio (R_b) It is the ratio of the number of streams of given order u to the number of streams of higher order u+1.

$$R_b = \frac{N_u}{N_{u+1}} \quad (1)$$

In general, lower values of R_b are characteristics of watershed which has suffered less structural disturbances and the drainage pattern has not been distorted by structural disturbances [4]. Steeply dipping rock strata exists, where R_b value is abnormally high. The value of R_b is also an indicator of basin shape. An elongated basin is likely to have high R_b, whereas low value of R_b shows circularity of basin.

Form Factor (R_f) It is the ratio of basin area A, to the square of maximum length of the basin L_b.

$$R_f = \frac{A}{L_b^2} \quad (2)$$

Elongation ratio (R_e) It is defined as the ratio between the diameter of a circle with the same area that of the basin to the maximum length of the basin, and is computed as

$$R_e = \frac{2}{L_b}\sqrt{\frac{A}{\Pi}} \quad (3)$$

In most of the climatic and geological environment elongation ratio varies from 0.6 to 1. Low relief area carries values of R_e near to 1, whereas values in the range of 0.6 to 0.8 are generally relates to high relief with steep ground slope. Elongated basins with high bifurcation ratios gives a low but extended peaks flow.

Circulatory ratio (R_c) It is the ratio of the watershed area to the area of circle of having equal perimeter as the perimeter watershed (P_r). Circular basins with low bifurcation ratio produce a sharp peak. It is computed as

$$R_c = \frac{12.57\ A}{P_r^2} \quad (4)$$

Drainage density (D_d) Drainage density is one of the important indicators of the linear scale of land form in stream eroded topography, and is defined as the ratio of total length of the streams of all orders of basin to the area of basin. D_d indicates the closeness of streams, which provides quantitative measure of mean length of stream channel for whole basin. Moreover idea about underlying rock can also be sought from D_d. Generally, highly resistant and permeable sub soil material is found in low drainage density area, where as high drainage density is prevalent in regions of weak, impermeable sub surface materials which are thinly vegetated and have high relief [11].

Drainage frequency (D_f) Drainage frequency is the number of streams per unit area of the basin. It mainly depends upon the lithology of the basin and reflects the texture of the drainage network.

Maximum Watershed Relief (H) It is the maximum vertical distance between the lowest and highest points of a watershed. It is also known as total relief.

Relief Ratio (R_h) It is the total relief of watershed divided by the maximum length of the watershed. It is an indicator of the potential energy available to move water and sediment down the slope.

Ruggedness Number (R_N) It is defined as the product of the maximum watershed relief and its drainage density. It gives an idea of overall roughness of a watershed, and is computed as

$$R_N = H \times D_d \quad (5)$$

For morphometric analysis, area, perimeter, maximum length of watershed, drainage network, stream length of each order, and number of streams of each order and watershed relief values is required. These inputs were derived in GIS environment. For morphometric analysis necessary parameters were estimated with above discussed formulae.

C. *Prioritization of sub watersheds*

The resource considerations for execution of watershed management program or various other reasons pertaining to administrative or even political consideration may limit the implementation to few sub watersheds. Even otherwise it is always better to start management measures from the highest priority sub watersheds, which makes it mandatory to prioritize the sub watersheds available. Watershed prioritization is thus ranking of different sub watersheds according to the order in which they have to be taken for treatment and soil conservation measures. Hence it was necessary to develop suitable mechanism for prioritizing the sub watersheds. Morphometric analysis is a significant tool for prioritization of micro-watersheds even without considering the soil map [1].

The parameters drainage density, drainage frequency, form factor, circulatory ratio, elongation ratio, bifurcation ratio, ruggedness number and relief ratio are also termed as erosion risk assessment parameters [12] and these parameters have been used this study for prioritizing sub watersheds for conservation measures. For prioritization the highest value of bifurcation ratio, drainage density, drainage frequency, relief ratio and ruggedness number has given the first rank and the lowest value was rated least in the serial number. For the parameters form factor, circulatory ratio and elongation ratio least value was rated first rank and the highest value was given the last rank. The lowest compound parameter value is given the highest priority for final prioritization rating of sub watersheds.

III. 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 1 & 2 and computed geomorphometric parameters are listed in Table 3 & 4 respectively.

The maximum length of sub-watersheds of Khurji nala and Dala nala watersheds is presented in Table 1 and 2 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 Khurji nala watershed. In Dala nala watershed, sub-watershed 7 has a largest maximum length of watershed i.e. 7.29 km, whereas, sub-watershed 2 has the minimum value i.e., 1.83 km.

The bifurcation ratio (R_b) reflects geological and tectonic characteristics of watershed area were calculated for sub-watersheds of Khurji nala and Dala nala watersheds and are given in Table 3 and 4 respectively. These values more or less normal for both the watersheds as they ranges between1 and 3 [3]. Higher values of R_b for sub watersheds indicates high runoff low recharge and mature topography and is expected in the region of steeply dipping rock strata where narrow valley is confined between the ridges. (Less structural control occurs in the region having low value of Rb. The variation in R_b values among the drainage basins are attributed to the differences in various stages of geomorphic development and topographic variations.

In general shape of the basin affects the stream flow hydrographs and peak flows. The important parameters that describe the shape of the basin i.e. Form factor, Circulatory ratio and Elongation ratio were computed for both the watersheds (Table 3 and 4). The value of Form factor would always be less than 0.7854 (for perfectly circular basin). The smaller the value of Form factor more elongated will be the basin. The basin with high Form factor have high peak flows of shorter duration, where as with low Form factor have lower peak flows of longer duration. In the present study sub-watersheds of both watersheds have lower R_f values 0.142 to 0.565 for Khurji nala watershed and 0.243 to 0.435 for Dala nala watershed indicating them to be elongated in shape and suggesting flatter peak flow for longer duration. Flood flows of such elongated basins are easier to manage than those of circular basin. Circulatory ratio (R_c) is influenced by the length and frequency of streams, geological structures, land use / land cover, climate, relief and slope of the basin. In the present case Circulatory ratios for sub-watersheds of Khurji nala are 0.273 to 0.626 and for Dala nala 0.327 to 0.772, indicating that the drainage system is structurally controlled. R_e values for sub-watersheds of Khurji nala varies between 0.425 and 0.848 and for Dala nala 0.516 to 0.745, indicates sub watersheds to be elongated with high relief and steep slopes. Relief ratio (R_h) and Ruggedness number (R_N) values for all the sub-watersheds of both the watersheds are given in Table 3 and 4. Sub watersheds with high R_h are considered critical from erosion point of view and should be provided with suitable soil and water conservation measures. The Ruggedness number (R_N) for sub-watersheds of Khurji nala watershed ranges from 0.246 to 0.842, which shows that sub-watershed 3 has an overall roughness among other sub-watersheds. However, in case of sub-watersheds of Dala nala R_N values ranges from 0.039 to 0.607, so sub-watershed 1 has among all sub-watersheds ,an overall roughness or unevenness.

Drainage density (D_d) and Drainage frequency (D_f) are computed for all the sub-watersheds of Khurji nala and Dala nala watershed and are given in Table 3 and 4. Drainage frequency values of all the sub watersheds have close correlation with Drainage density indicating the increase in stream population with respect to increase in Drainage density. High value of D_f in the sub- watershed 1 of Khurji nala and sub-watershed 2 of Dala nala, produces more runoff compared to others. In general it has been observed over wide range of geologic and climatic types that low D_d is more likely to occur in regions of highly permeable sub soil material under dense vegetation cover and where relief is low. In contrast high D_d is favored in regions of weak or impermeable subsurface material, sparse vegetation and mountainous relief [4]. In the present study low value of D_d for sub-watershed5 of Khurji nala and sub-watershed 7 of Dala nala, indicates that it has highly resistant, impermeable sub soil material with dense vegetation cover and low relief. The sub-watershed with high value of D_d indicates well developed network, which is conducive for quick disposal of runoff resulting in intense floods and characterized by a region of weak sub surface materials, high relief and sparse vegetation.

To facilitate the phase wise implementation, all the sub-watersheds of both the watershed are prioritized on the basis of morphometric analysis. The compound parameter values of sub- watersheds of Khurji nala and Dala nala are calculated and prioritization rating is shown in Table 5 and 6. The sub-watershed 1 of Khurji nala watershed with a compound parameter value of 2.25 receives the highest priority (one) with the next in the priority is sub watershed 4 having the compound parameter value of 2.75. However for Dala nala watershed, sub-watershed 1 and 5 with compound parameter value of 2.87 receives the highest priority (one) with the next in the priority is sub-watershed 3 with compound parameter value 3. Highest priority indicates the greater degree of erosion in the particular sub-watershed and it becomes potential candidate for applying soil conservation measures. Thus, soil conservation measures can first be applied to the top priority sub-watershed and then to other depending on their priority.

Table 1 Sub-watersheds wise input parameters derived in GIS environment of Khurji nala watershed

Subwat 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 2 Sub-watersheds wise input parameters derived in GIS environment of Dala nala watershed

Subwat 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

Table 3 Sub watershed-wise computed morphometric parameters of Khurji nala watershed

Subwat no.	R_b	R_f	R_e	R_c	D_d	D_f	R_h	R_N
1	2.753	0.273	0.590	0.617	5.610	9.221	0.073	0.819
2	2.501	0.329	0.647	0.613	3.626	4.613	0.023	0.199
3	3.001	0.565	0.848	0.626	5.579	8.328	0.063	0.842
4	2.662	0.257	0.572	0.478	4.240	5.829	0.058	0.670
5	2.902	0.142	0.425	0.273	1.457	0.591	0.019	0.246

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

Subwat no.	R_b	R_f	R_e	R_c	D_d	D_f	R_h	R_N
1	3.625	0.360	0.677	0.635	3.591	4.674	0.052	0.607
2	2.250	0.435	0.745	0.772	3.772	5.672	0.041	0.287
3	5.250	0.259	0.574	0.414	3.545	4.231	0.030	0.589
4	2.250	0.209	0.516	0.516	1.965	1.859	0.010	0.090
5	3.750	0.243	0.557	0.495	3.501	4.141	0.046	0.595
6	2.500	0.429	0.739	0.637	3.478	5.031	0.047	0.330
7	1.389	0.373	0.690	0.327	1.338	0.855	0.004	0.039

Table 5 Prioritization of sub-watersheds of Khurji nala watershed

Sws no.	R_b	R_f	R_e	R_c	D_d	D_f	R_h	R_N	Compound Parameter	Final Priority
1	3	3	3	4	1	1	1	2	2.25	1
2	5	4	4	3	4	4	4	5	4.12	5
3	1	5	5	5	2	2	2	1	2.87	3
4	4	2	2	2	3	3	3	3	2.75	2
5	2	1	1	1	5	5	5	4	3	4

Table 6 Prioritization of sub-watersheds of Dala nala watershed

Sws no.	R_b	R_f	R_e	R_c	D_d	D_f	R_h	R_N	Compound Parameter	Final Priority
1	3	4	4	5	2	3	1	1	2.87	1
2	5	7	7	7	1	1	4	5	4.62	4
3	1	3	3	2	3	4	5	3	3.00	2
4	5	1	1	4	6	6	6	6	4.37	3
5	2	2	2	3	4	5	3	2	2.87	1
6	4	6	6	6	5	2	2	4	4.37	3
7	7	5	5	1	7	7	7	7	5.75	5

I. CONCLUSION

The quantitative morphometric analysis was carried out in sub-watersheds of Khurji nala and Dala watersheds of Gour river basin using RS and GIS technique for determining the linear, relief and areal aspects. The conventional methods of morphometric analysis are time consuming, tiresome and error prone, while use of RS and GIS technique allows for more reliable and accurate estimation of similar parameters of watersheds. The morphometric analysis of different sub watersheds shows their relative characteristics with respect to hydrologic response of the watershed. The result of morphometric analysis shows that sub-watershed 1 of Khurji nala watershed and sub-watershed 1 and 5 of Dala nala are prone to relatively higher erosion and soil loss. Hence, suitable soil erosion control measures are required in these sub watersheds to preserve the land from further erosion.

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