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WATERSHED PRIORITIZATION OF MICRO-WATERSHEDS THROUGH MORPHOMETRIC ANALYSIS: A REMOTE SENSING AND GIS PERSPECTIVE

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ABSTRACT
The development of new advanced techniques in Spatial Information such as remote sensing and GIS are effectively used for the extraction of information about spatial features. DEM (Digital Elevation Model) is one of the important sources in extraction of drainage network and is useful for determining the quantitative description of catchment geometry *i.e.* morphometric analysis. Morphometric analysis has been commonly applied to prioritization of watersheds. The quantitative analysis of drainage system is an important aspect of characterization of watersheds. Using watershed as a basic unit in morphometric analysis is the most logical choice because all hydrologic and geomorphic processes occur within the watershed. The present study makes an attempt to prioritize six inaccessible micro-watersheds of Maniari river catchment of Mungeli district, Chhattisgarh on morphometric analysis, using remote sensing and GIS perspective. These have been classified into three priority categories as high, medium and low for conservation and management. Two micro-watersheds viz., 4G3F4n1 and 4G3F4n6 qualify for high priority watersheds and are likely to be subjected to maximum soil erosion and susceptible to natural hazards. Micro-watersheds 4G3F4n4 and 4G3F4n5 have been categorized as under medium priority watersheds and 4G3F4n2 and 4G3F4n3 as low priority category. Watersheds categorized as high priority have been proposed for conservation treatments.

KEYWORDS: Watershed. GIS. Remote sensing. Morphometric analysis. Prioritization

INTRODUCTION

Watershed is an ideal unit for management and sustain-able development of natural resources (Patel *et al.* 2012). It is a natural hydrological entity which allows surface runoff to a defined channel, drain, stream or river at a particular point (Chopra *et al.* 2005). Watershed man-agement is the process of formulation carrying out a course of action that involves modification in the natural system of watershed to achieve specified objectives (Johnson *et al.* 2002). It further implies appropriate use of land and water resources of a watershed for optimum production with minimum hazard to natural resources (Osborne and Wiley 1988; Kessler *et al.* 1992). Morphometric analysis helps in better understanding of drainage morphometry on landforms and catchment characteristics (Sreedevi *et al.* 2009). Catchments are geographical drainage areas of the land surface that contribute flow to outlet point. Study of Catchment characteristics plays an important role in the hydrological response of the catchment. The accurate delineation of the catchment boundaries is the first important step in the determination of stream flow path and its contributing area. Remote sensing and GIS are effective tools in extraction of spatial information particularly for the delineation of catchment boundaries (Ahmed *et al*. 2010; Bertolo, 2000). In recent years the use of GIS (Geographic Information System) has become increasingly popular and has facilitated much of the work of hydrologists in the scientific study and management of water resources. The use of DEMs (Digital Elevation Models) in particular has made watershed delineation a relatively smooth procedure. DEM provide good terrain representation from which the watersheds can be derived automatically using GIS technology. The techniques for automated watershed delineation have been available since mideighties and have been implemented in various GIS systems and custom applications (Garbrecht and Martz, 1999). The present study involves the application of geospatial technique to delineate the catchment boundary and evaluation of morphometric parameters derived from DEM. The morphometric parameters include basic parameters and derived parameters. The basic parameters are catchment area, perimeter, basin length, maximum and minimum elevations and slope. The derived parameters for Prioritization considered are linear (Stream order, Stream length, Stream length ratio and Bifurcation ratio) and areal

(Drainage density, Stream frequency, Texture ratio, Elongation ratio, Circularity ratio and Form factor). The main aim of the present study is to delineate and analyze all the morphometric features derived from DEM and to establish the superiority and easiness of remote sensing and GIS techniques in deriving the morphometric features.

STUDY AREA

Sardha Small watershed is situated in Lormi block of Mungeli district and located between 21^0 11'0" to 210 20'0" N latitudes and $81^0$37'0" to $81^0$49'0" E longitudes (Fig 1). It falls in SOI topographical map no. 64 F/12(1:50,000). The Sardha watershed covers geographical area of 80.59 Km^2. The general elevation of the area ranges from 264 to 337 m above mean sea level (MSL).

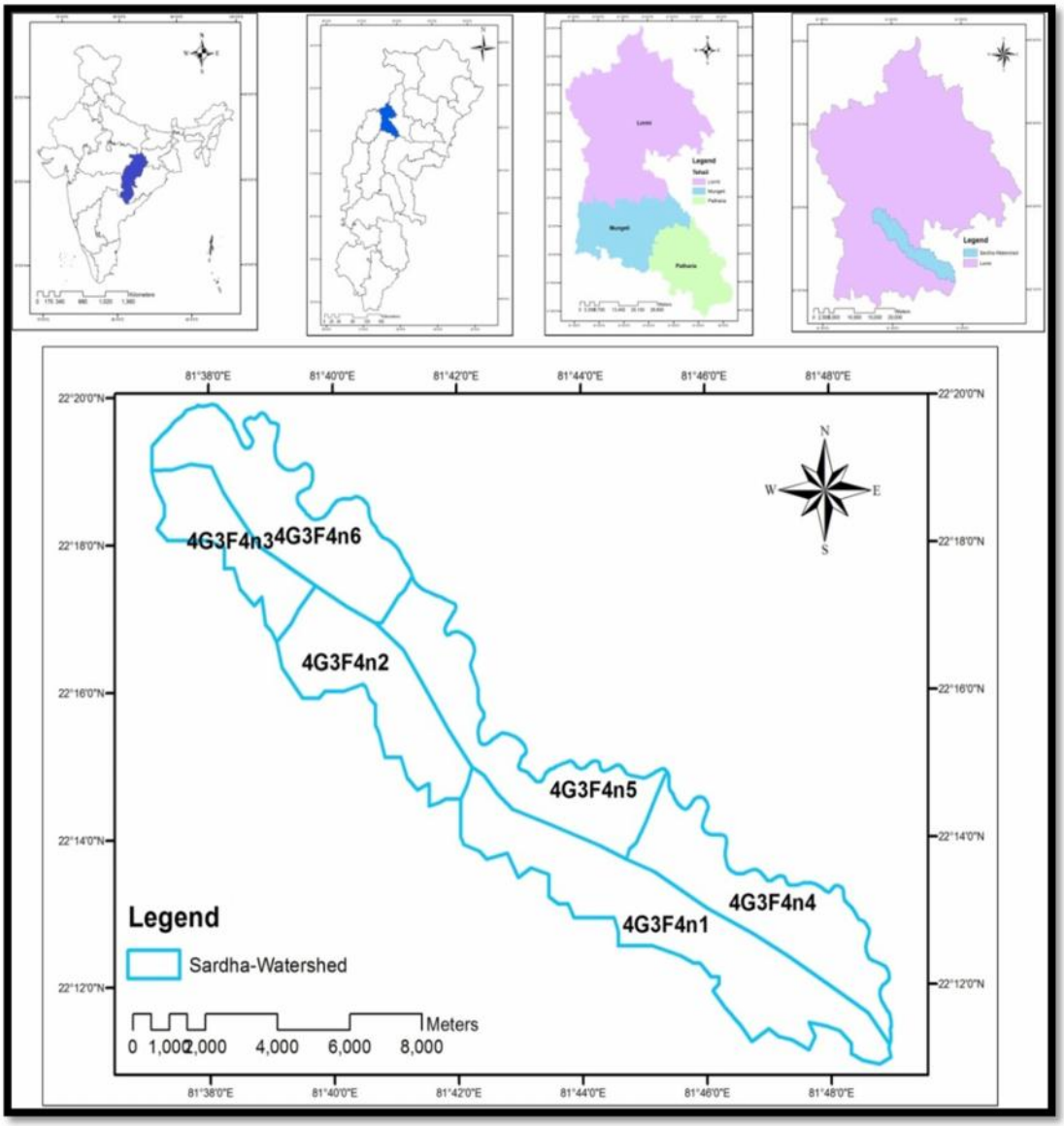

Figure 1: Layout of the study area

MATERIALS AND METHODS

The base map for morphometric analysis of the Maniari River was prepared from Survey of India topographical maps no. 64 F/12 (1: 50,000). The hard copy of topographic map was scanned using a wide format scanner and exported in ERDAS IMAGINE 2011 where it was georefernced. After georeferencing onscreen digitization process was carried out using ARC GIS 10 to extract stream network (Fig.3). The designation of the stream order is the first step in morphometric analysis of a drainage basin, which is based on the hierarchy ranking of streams proposed by Strahler (1964). Sardha sub-watershed is divided into six micro-watersheds, (Fig.1) digitized from topographic map, were designated as 4G3F4n1 to 4G3F4n6. Computation of basin parameters required for morphometric analysis, ordering, lengths, area etc. were estimated using GIS technique, which were later used to calculate other parameters like drainage density, stream frequency, bifurcation ratio, drainage

texture, length of overland flow, form factor, circularity ratio, elongation ratio and basin shape for each micro-watersheds.

These parameters were evaluated with the help of standard mathematical equations as mentioned in table 1. Prioritization of micro-watersheds was carried out by assigning weight factors to all the computed morphometric parameter. ThevDEM (Fig.4) is the digital representation of the topographic surface. DEM was prepared using contour lines and elevation points extracted from SOI toposheets and additional attributes observed from GPS. The digitized vectors were gridded using programme available in ArcGIS 10 to convert vectored input into grids. Like contour map it represents the elevation values in meters. The grids were interpolated using the Raster interpolation (topo to raster) method available in 3D analysist option in toolbox. The methodology used in this study is shown in fig. 2.

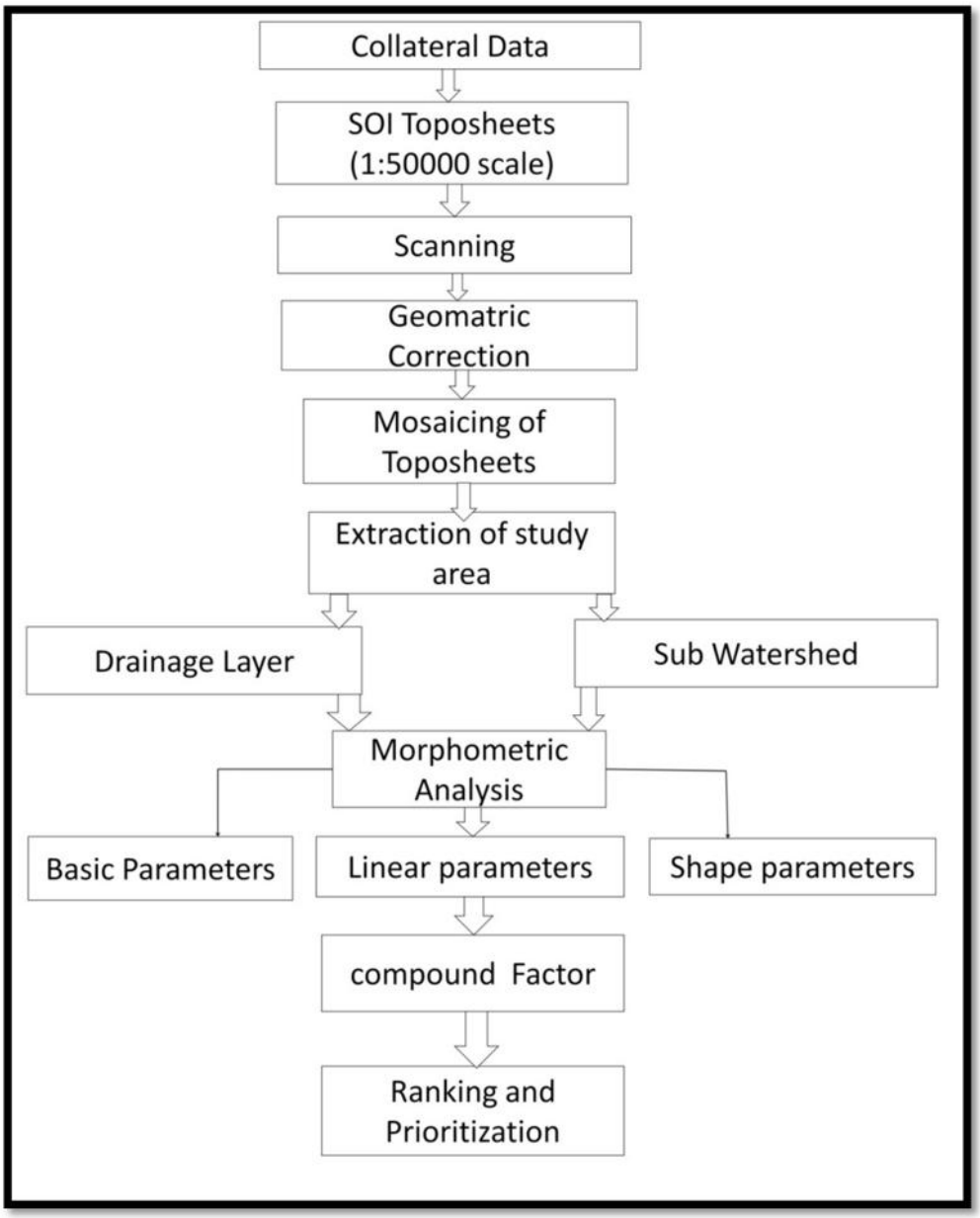

Figure 2: Flowchat of the methodology used in this study

Table 1: Empirical relationships used in computation of morpho-metric parameters

Morphometric parameter	Formula	Reference
Stream order	Hierarchial rank	Strahler (1964)
Stream length (L_u)	Length of stream	Horton (1945)
Mean stream length (L_{sm})	$L_{sm} = L_u/N_u$ where, L_{sm} = mean stream length L_u = Total stream length of order 'u' N_u = Total no. of stream segments of order 'u'	Horton (1945)
Stream length ratio (R_L)	$RL = L_u / L_{u-1}$ where, R_L = stream length ratio L_u = Total stream length of order 'u' L_{u-1} = Total stream length of its next lower order	Horton (1945)
Bifurcation ratio (R_b)	$R_b = N_u / N_{u+1}$ R_b = Bifurcation ratio N_u = Total no. of stream segments of order 'u' N_{u+1} = no. of stream segments of the next higherorder	Schumm (1956)
Mean bifurcation ratio(R_{bm})	R_{bm} = Average of bifurcation ratios of all orders	Strahler (1957)
Basin length (L_b)	$L_b = 1.321A^{0.568}$ where, A= Area of the basin	Nookaratnam (2005)
Drainage density (D_d)	$D_d = L_u /A$ where, D_d = Drainage density L_u = Total stream length of all orders A = Area of basin (km^2)	Horton (1932)
Stream frequency (F_s)	$F_s = N_u / A$ where F_s = Stream frequency N_u = Total no. of streams of all orders A = Area of basin (km^2)	Horton (1932)
Texture ratio (R_t)	$R_t = N_u / p$ where, R_t = Texture ratio N_u = Total no. of streams of all orders P = Perimeter (km)	Horton (1945)
Form factor (R_f)	$R_f = A/L_b^2$ where, A = Area of basin (km^2) L_b^2 = Square of basin length	Horton (1932)
Shape factor (B_s)	$B_s = L_b^2/A^h$ where, L_b = Square of basin length A= Area of basin (km^2)	Nookaratnam (2005)
Circulatory ratio (R_c)	$Rc = 4 \times \pi \times A / P^2$ where, R_c = circulatory ratio A = Area of basin (km^2) P = Square of the perimeter (km)	Miller (1953)
Elongation ratio (R_e)	$R_e = (4 \times A / \pi)^{0.5} / L_b$ where, Re = Elongation Ratio A = Area of basin (km2) L_b = Basin length	Schumm (1956)
Length of overland flow (L_g)	$Lg = 1/2D_d$ where, L_g = Length of overland flow D_d = Drainage Density	Horton (1945)
Compactness constant (C_c)	$C_c = 0.2821P/A^{0.5}$ where, A = Area of basin (km2) P = Perimeter (km)	Horton (1945)

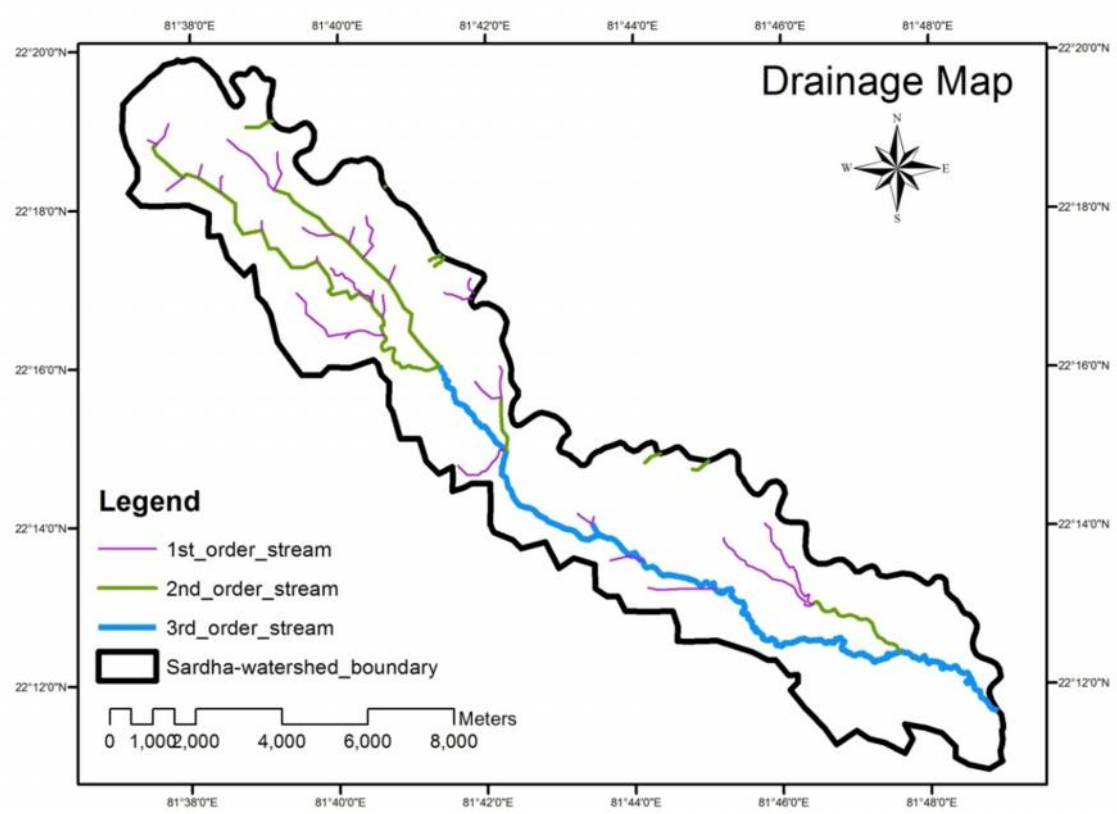

Figure 3: Drainage map of the study area

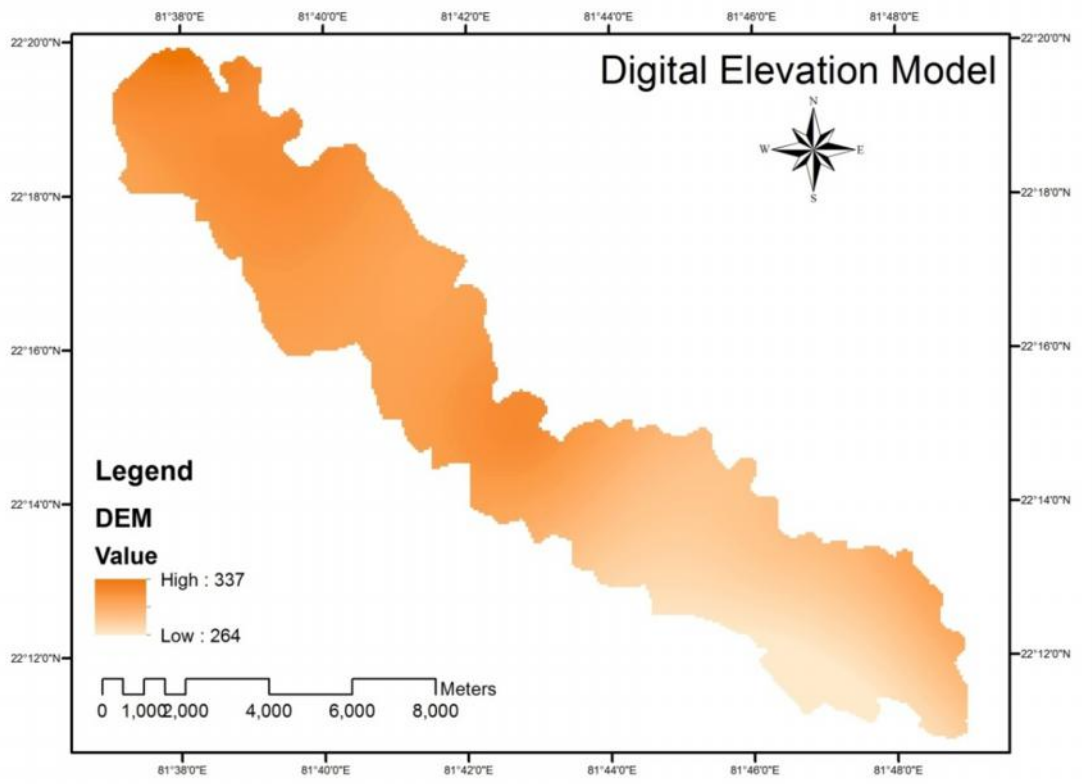

Figure 4: Digital elevation model map of the study area

RESULTS AND DISCUSSION

Morphometric analysis

The information about basic morphometric parameters such as area (A), perimeter (P), length (L), and number of streams (N) was obtained from sub watershed delineated layer, and basin length (L_b) was calculated from stream length, while the bifurcation ratio (R_b) was calculated from the number of streams. Other morphometric parameters were calculated using the equations as described in Table 1. Linear parameters have a direct relationship with erodibility (Nooka Ratnam *et al.* 2005). Higher the value, higher is the erodibility. For prioritization of micro-watersheds, the highest value of linear parameters was rated as rank 1, second highest value was rated as rank 2 and so on, and the least value was rated last in rank. On the contrary, the shape parameters have an inverse relation with linear parameters, so that the lower their value, the more the erodibility (Patel and Dholakia, 2010; Patel *et al.* 2012). Thus the lowest value of shape parameters was rated as rank 1, next lower value was rated as rank 2 and so on and the highest value was rated last in rank. Compound factor was then worked out by summing all the ranks of linear parameters as well as shape parameters and then dividing by number of parameters. From the group of mini-watersheds, highest prioritized rank was assigned to micro-watershed having lowest compound factor and vice versa (Patel *et al.* 2012). Basic parameters Basic parameters include watershed area, perimeter, stream length, stream order, and basin length.

Area

The rate of runoff of any drainage basin depends on its area and physiography. The drainage basin area is a dimensional parameter and it is denoted by A. The drainage basin is instrumental in governing the rate at which water is supplied to the main stream as it precedes to the outlet. Area of basin of a particular order is defined as the total area projected upon a horizontal plane, contributing overland flow to the channel segment of a given order including all the tributaries of the lower order. The factors which are dependent on the basin length are length of stream, degree of slope, drainage frequency, drainage density, shape parameters (i.e. form factor, circulatory ratio and elongation ratio), rainfall, rate of runoff etc. Larger the area, smaller is the runoff and vice versa. The basin Area of different micro-watersheds is given in Table 3

Perimeter

Total Length boundary of a basin is known as the perimeter of the basin and it is denoted by P. The factors that are dependent on the basin parameter are elongation ratio and circulatory ratio. Earlier, the perimeter was measured with chartometer (a map measurer). All segments within the specified drainage network were used to measure successively without pause or recorded the cumulative length appeared on the dial of the chartometer. Perimeters of different micro-watersheds were derived from GIS software that gives the perimeter of each polygon. The basin Perimeters of different micro-watersheds are given in Table 3.

Basin Length

It is the length of longest dimension of a basin as projected on a horizontal plane and it is denoted by L_b. As the basin length increases, the peak discharge decreases. The basin lengths of different micro-watersheds are given in Table 3.

Stream Order

The designation of stream orders is the first step in drainage basin analysis. It is based on hierarchic ranking of streams proposed by (Strahler, 1964). The first order streams have no tributaries. The second order streams have only first order streams as tributaries. Similarly, third order streams have first and second order streams as tributaries and so on. After analysis of the drainage map, it is found that Sardha watershed is 3rd order stream and drainage pattern is dendrite. The basins Stream Order of different micro-watersheds are given in Table 2.

Stream Length

It is the total length of streams in a particular order and it is denoted as Lu. The numbers of streams of various orders in a micro-watershed were counted and their lengths measured in GIS. Generally, the total length of stream segments decrease with stream order. Length of different drain segments have been extracted in GIS and presented in Table 2. Higher length of streams in micro -watersheds revealed good morphologic characteristics. Table 3 shows that in Total length of stream of micro- watersheds value ranges from 10.16 km to 29.02 km for the micro-watersheds.

Basin length (L_b)

It is usually defined as the distance measured along the main channel from the watershed outlet to the basin-divide. Since the channel does not extend to the basin-divide, it is necessary to extend a line from the end of the channel to the basin-divide following a path where the greatest volume of water would travel. Thus, the length is measured along the principal flow path. Basin length is the basic input parameter to count the major shape parameters. Table 3 shows that in Basin length (L_b) of micro-watersheds value ranges from 3.90 km to 7.28 km for micro-watersheds 4G3F4n3 and 4G3F4n1 respectively.

Table 2: Micro-watershed wise areal parameters

S.No.	Micro Watershed	Area (km^2)	Perimetes (km)	Number of Streams			Stream Length in km		
				1st	2nd	3rd	1st	2nd	3rd
1	4G3F4n1	20.45	32.81	4	2	2	2.94	0.33	16.18
2	4G3F4n2	11.57	17.71	10	3	1	6.67	19.58	2.77
3	4G3F4n3	6.79	14.77	6	1	0	2.44	7.72	0
4	4G3F4n4	13.54	23.66	4	2	2	5.38	2.64	16.93

5	4G3F4n5	13.72	26.34	6	6	0	2.66	8.66	0
6	4G3F4n6	14.51	23.40	8	3	0	5.34	6.53	0

Table 3: Morphometric parameters of micro-watershed

Micro Watershed	Area (km^2)	Perimeters (Km)	Elevation(m)		Basin Length (km)	Total Relief (m)	Number of Streams	Total Stream Length (km)
			Max	Min				
4G3F4n1	20.45	32.81	321.05	264.30	7.28	56.74	8	19.45
4G3F4n2	11.57	17.71	320.06	309.24	5.27	10.82	14	29.02
4G3F4n3	6.79	14.77	320.22	310.47	3.90	9.75	7	10.16
4G3F4n4	13.54	23.66	310.35	286.27	5.76	24.08	8	24.95
4G3F4n5	13.72	26.34	322.53	290.30	5.81	32.22	12	11.32
4G3F4n6	14.51	23.40	335.97	309.79	6.00	26.18	11	11.87

Linear parameters include bifurcation ratio, drainage density, stream frequency, texture ratio, and length of overland flow.

Bifurcation Ratio

It is the ratio of the numbers of streams of a given order to the number of streams of the next higher order. Horton (1945) considered bifurcation ratio (Rb) as an index of relief and dissections. Strahler (1957) demonstrated that Rb shows only a small variation for different region on different environment except where powerful geological control dominates. Lower Rb values are the characteristic of structurally less distributed watersheds without any distortion in drainage pattern (Nag, 1998). Higher value of Rb for micro-watershed indicates high runoff, low recharge and mature topography. A high Rb is expected in the region of steeply digging rock strata, where narrow valley is confined between the ridges. Irregular Rb values in these micro-watersheds do not subscribe to Horton‟s Law of stream numbers. These irregularities are dependent on geological and lithological development of drainage basin (Strahler, 1964). Table 4 shows that in mean bifurcation ratios (R_b) of the micro-watersheds values ranges from 2.83 to 3.67 for the micro-watersheds with lowest value for micro-watershed no 4G3F4n6 and highest value for the micro-watershed no 4G3F4n2 respectively.

Drainage Density

Drainage density (Dd) expresses the closeness of spacing of channels. It is the measure of the total length of the stream segment of all orders per unit area. It is affected by factors which control the characteristic length of the stream like resistance to weathering, permeability of rock formation, climate, vegetation etc. In general, low value of Dd is observed in regions underlain by highly resistant permeable material with vegetative cover and low relief. High drainage density is observed in region of weak and impermeable subsurface material and sparse vegetation and mountainous relief. Table 4 shows that in Drainage Density (Dd) of micro- watersheds value ranges from 0.82 to 2.5 for micro-watersheds with lowest value for micro-watershed no 4G3F4n6 and highest value for the micro-watershed no 4G3F4n2 respectively.

Length of Overland Flow

It is the length of water over the ground before it gets concentrated into definite stream channels (Horton, 1945). This factor relates inversely to the average slope of the channel and is quite synonymous with the length of sheet flow to a large degree. It approximately equals to half of reciprocal of drainage density. Table 4 shows that the Length of Overland Flow (Lg) of Micro-watersheds value ranges from 0.41 to 1.25 for micro-watersheds with lowest value for micro-watershed no 4G3F4n6 and highest value for the micro-watershed no 4G3F4n2 respectively.

Stream/Drainage Frequency

Drainage frequency is the measure of the topographic feature. Stream frequency/drainage frequency (fs) is the total number of stream segments of all orders per unit area (Horton, 1932). Table 4 shows that in Stream/Drainage Frequency (fs) of Micro-watersheds value ranges from 0.39 to 1.21 for micro-watersheds with lowest value for micro-watershed no 4G3F4n1 and highest value for the micro-watershed no 4G3F4n2 respectively.

Texture ratio

It is the total number of stream segment of all orders per perimeter of that area (Horton, 1945). Horton recognized infiltration capacity as the single important factor which influences Texture ratio (R_t) and considered the drainage texture to include drainage density and drainage frequency. Table 4 shows that in Texture ratio (R_t) of micro- watersheds value ranges from 0.24 to 0.24 for micro-watersheds with lowest value for micro-watershed no 4G3F4n1 and highest value for the micro-watershed no 4G3F4n2 respectively.

Shape parameters Shape parameters include form factor, shape factor, elongation ratio, compactness ratio, and circulatory ratio.

Form Factor

It is defined as the ratio of basin area to square of the basin length (Horton, 1932). The value of form factor would always be less than 0.7854 (for a perfectly circular basin). Smaller the value of form factor, more elongated will be the basin. The basins with high form factor have high peak flows of shorter durations, whereas, elongated micro-watershed with low form factor have lower peak flow of

longer duration. Flood flows of such elongated basins are easier to manage than of the circular basin. Table 4 shows that in form factor (Rf) of micro-watersheds value ranges from 0.39 to 0.45 for micro-watersheds with lowest value for micro-watershed no 4G3F4n1 and highest value for the micro-watershed no 4G3F4n3 respectively.

Shape factor

It is defined as the ratio of the square of the basin length to area of the basin (Horton 1945) and is in inverse proportion with form factor (R_f). Table 4 shows that in shape factor (B_S) of Micro-watersheds value ranges from 2.23 to 2.59 for micro-watersheds with lowest value for micro-watershed no 4G3F4n3 and highest value for the micro-watershed no 4G3F4n1 respectively.

Elongation Ratio

It is the ratio between the drainage of the circle of the same area as the drainage basin and the maximum length of the basin. A circular basin is more efficient in runoff discharge than a elongated basin (Singh and Singh, 1997). The value of elongation ratio (Re) generally varies from 0.6 to 1.0 associated with a wide variety of climate and geology. Values close to 1.0 are typical of regions of very low relief whereas that of 0.1 to 0.8 are associated with high relief and steep ground slope (Strahler, 1964). Table 4 shows that in elongation ratio (Re) of micro-watersheds value ranges from 0.70 to 0.76 for micro-watersheds with lowest value for micro-watershed no 4G3F4n1 and highest value for the micro-watershed no 4G3F4n3 respectively.

Compactness coefficient (C_c)

Compactness coefficient (C_c) can be represented as basin perimeter divided by the circumference of a circle to the same area of the basin and also known as the Gravelius index (GI). Lower values of this parameter indicate more elongation of the basin and less erosion, while higher values indicate less elongation and high erosion. In this study, Table 4 shows that in Compactness coefficient (C_c) of micro-watersheds value ranges from 1.47 to 2.05 for micro-watersheds with lowest value for micro-watershed no 4G3F4n2 and highest value for the micro-watershed no 4G3F4n1 respectively.

Circulatory Ratio

It is ratio of the area of the basin to the area of circle having the same circumference as the perimeter of the basin (Miller, 1953). It is influenced by the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin Table - 4 shows that in circulatory ratio (Rc) of micro-watersheds value ranges from 0.24 to 0.46 for micro-watersheds with lowest value for micro-watershed no 4G3F4n1 and highest value for the micro-watershed no 4G3F4n2 respectively. micro-watersheds having circular to oval shape allows quick runoff and results in a high peaked and narrow hydrograph, while elongated shape of micro-watersheds allows slow disposal of water, and results in a broad and low peaked hydrograph. High value of Rc indicates mature and old topography.

Table 4 Analyzed morphometric parameters

Morphometric Parameters										
	Linear Parameters					Shape Parameters				
Micro Watershed	R_b	D_d	F_s	L_g	T	R_c	R_f	B_s	R_e	C_c
4G3F4n1	3.00	0.95	0.39	0.48	0.24	0.24	0.39	2.59	0.70	2.05
4G3F4n2	3.67	2.51	1.21	1.25	0.24	0.46	0.42	2.40	0.73	1.47
4G3F4n3	3.50	1.50	1.03	0.75	0.47	0.39	0.45	2.23	0.76	1.60
4G3F4n4	3.00	1.84	0.59	0.92	0.34	0.30	0.41	2.45	0.72	1.81
4G3F4n5	3.50	0.83	0.87	0.41	0.46	0.25	0.41	2.46	0.72	2.01
4G3F4n6	2.83	0.82	0.76	0.41	0.47	0.33	0.40	2.48	0.72	1.73

Prioritization of Sub Watersheds Based on morphometric analysis

The response of a watershed to different hydrological processes and its behavior depends upon various physiographic, hydrogeological and geomorphological parameters. Though these are watershed specific and there by unique, the prioritization of a watershed provides an idea about its behavior. Considering the massive investment in the watershed development programs, it is important to plan the activities on priority basis for achieving fruitful results, which also facilitate addressing the problematic areas to arrive at suitable solutions. For prioritization, the compound factor is computed by summing all the ranks of linear parameters as well as shape parameters and then dividing by the number of parameters. From the group of these micro-watersheds, highest rank was assigned to the micro-watershed having the lowest compound factor and so on. Depending upon the value of compound factor, ranking to each micro-watershed is assigned as shown in Fig. 5. For micro-watersheds, watershed no. 4G3F4n2 is given rank 1 with least compound factor value 2.1, followed by watersheds no. 4G3F4n3 and 4G3F4n4 as second and third, respectively. The values of compound factor and respective rank of all micro-watersheds are shown in Table 5.

Table 5 Calculation of compound factor and prioritized ranks

Morphometric Parameters												
	Linear Parameters					Shape Parameters						
Micro Watershed	R_b	D_d	F_s	L_g	T	R_c	R_f	B_s	R_e	C_c	Compound Factor	Prioritized Ranks
4G3F4n1	3	4	6	4	5	1	1	6	1	6	3.7	5
4G3F4n2	1	1	1	1	1	6	4	2	3	1	2.1	1
4G3F4n3	2	3	2	3	2	5	5	1	4	2	2.9	2
4G3F4n4	3	2	5	2	4	3	3	3	2	4	3.1	3
4G3F4n5	2	5	3	5	3	2	3	4	2	5	3.4	4
4G3F4n6	4	6	4	5	2	4	2	5	2	3	3.7	5

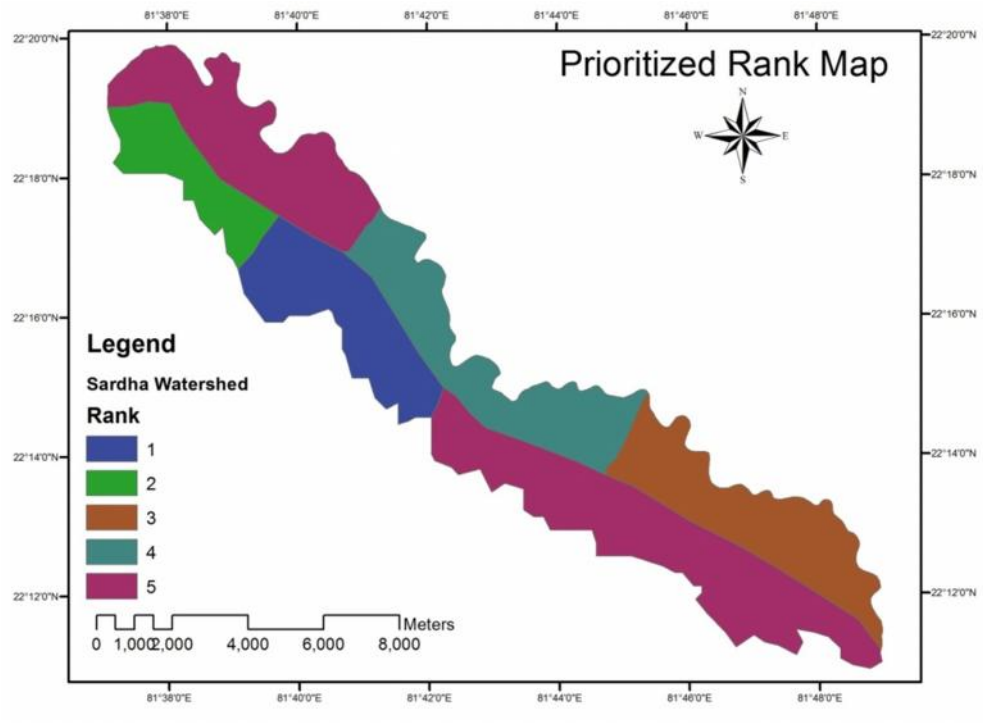

Fig. 5 Prioritized rank map of the study area

CONCLUSIONS

The present study reveals the effectiveness of Remote Sensing and GIS techniques for morphometric analysis of micro-watersheds of Maniari river catchment of Mungeli district, Chhattisgarh. The morphometric characteristics of different micro-watersheds show their relative influence on hydrologic response of the micro-watershed. The various morphometric parameters of each micro-watershed were ranked based on their susceptibility to run-off and erosion. 4G3F4n2 is found to be most vulnerable to high peak flows and erosion. This calls for setting up of immediate and viable remedial strategies for soil conservation and flood management. The present study further demonstrates the utility of Remote Sensing and GIS techniques in prioritization of watersheds, which may be helpful for taking the high priority implementation of soil and water conservation measures.

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