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Geomorphological parameters of the Arang watershed in Chhattisgarh region

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ABSTRACT : This study was conducted for the Arang watershed of the Chhattisgarh, India. Several geomorphological parameters of the watershed were determined using standard procedure. The Arang is 3rd order watershed and comprises of 10 villages. Predominant soil of the watershed is clay loam. The watershed receives an average annual rainfall of 1400 mm, out of which the monsoon season (June to October) contributes more than 85% rainfall. The number of 1st, 2nd and 3rd Order were found to be 20,4,1, respectively. The different geomorphometric parameters of watershed were determined and result showed that total length of stream segments were 26.14, 9.37, 8.56 km, respectively. Area of sub-basin for 1st, 2nd and 3rd order streams and of different order streams were to be 32.35, 43.94, and 54.50 km^2, respectively, for 1st, 2nd and 3rd order streams. The mean bifurcation ratio for the watershed was found to be 4.64. The length ratio, circularity ratio and elongation ratio for the Arang watershed were determined and found to be 2.724, 0.9148 and 0.973, respectively. The hypsometric integral of the watershed was calculated to be 0.998 km. The drainage density, length of over land flow and constant of channel maintenance of the watershed were found to be 0.808 km/km^2, 0.618 km and 1.237 km, respectively. The main channel slope of the watershed was 0.005 where as compactness co-efficient of the watershed was 1.093. The stream frequency, basin shape factor, form factor, and ruggedness number of the watershed were 0.458 km^2, 2.578, 0.387, 0701 and 0.016, respectively. The values of relative relief and relative ratio of the watershed was found to be 1.452×10^{-3} and 1.687×10^{-3}, respectively. The weighted average slope of the entire watershed was found to be 1.5%. This parameter indicates that topography of watershed was flat.

KEY WORDS : Geomorphological parameters, Watershed

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Development and management of natural resources in sustainable manner is possible by adopting soil and water conservation program on watershed basis. Soil and water are very important for sustainable agriculture. The average annual rainfall of India is about 120 cm and 80 per cent of these occur only in monsoon season *i.e.* from July to October. The amount of rainfall annually through the four different types of weather phenomena southwest monsoon (74%), northeast monsoon (3%), pre-monsoon (13%), post-monsoon (10%). The distribution of rainfall varies with time and space, the analysis of rainfall become more important for soil conservation point of view. Estimation of runoff is important for designing the soil and water conservation structures (Nag, 1998). Remote sensing techniques using satellite imagery is an indispensable tool in morphometric analysis and ground water studies. The base map showing drainage details were prepared from toposheets of survey of India (SOI) and satellite imagery. Morphometric analysis using remote sensing techniques was carried out in Chakra River sub-basin of Manbazar Block, Purulia District, West Bengal state, India. The parameters worked out included bifurcation ratio, stream length, form factor, circulatory ratio and drainage density. Tripathi *et al*. (2002) conducted study for the Nagwan watershed of the Damodar Valley Corporation (DVC), Hazaribagh, Bihar, India. Geographical Information System (GIS) was used to extract the hydrological parameters of the watershed from the Remote Sensing and field data. It was found that the model can predict runoff reasonably well and is well suited for the Nagwan watershed. Design of conservation structures can be done and their effects on direct runoff can be evaluated using the model.

METHODOLOGY

Study area:

Arang watershed located in the Raipur district of Chhattisgarh state was selected for investigation. Arang watershed is located at about 45 km away from Raipur city towards Mahasmund district. The watershed boundary covering various villages namely Amethi, Khamtarai, Kalai, Jarauda, Chhatauna, Sandi, Kukra etc. The watershed lies between $81^0$54' to $82^0$0'E longitude and $21^0$12' to $21^0$16'N latitude. Topographic maps No. 64 G/15 and 64 G/16 of 1:50000 scale cover the entire watershed. The location map of study area is shown in Fig. A.

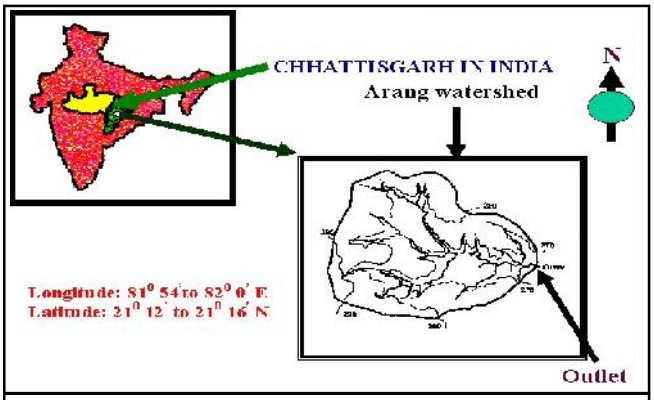

Fig. A : Location map of the Arang watershed in Chhattisgarh

Generation of thematic maps:

Various base maps such as watershed boundary, drainage network and contour maps were prepared using topographic map. Generation of drainage map, the drainage network gives an idea about the location of streams of various orders and density of streams. The drainage map was generated with the help of the toposheet for determining the various watershed parameters including drainage density, channel length and depth. Generation of digital elevation model (DEM) is a numerical representation of landscape topography. DEM can be used to derive a wealth of information about the morphology of land surface by means of algorithms in raster processing system, which uses neighborhood operations. These algorithms provide information such as flow direction, flow accumulation, drainage network, slope aspect and overland flow path. The DEM of the watershed was prepared using contour map of the study area. Contour interval of 10m was used in this study. The digitized vectors were gridded using TOPOGRID module available in Arc GIS to convert vector input into grids. The output after running the TOPOGRID module was the DEM. Previously generated DEM (Jadhao, 2004) were considered in this study for interaction of various morphological parameters.

Geomorphological analysis:

Geomorphologic characterization is the systematic description of watershed's geometry. Geometry of drainage basin and its stream channel system required the following measurements: (i) linear aspects of drainage network, (ii) aerial aspect of drainage basin, (iii) relief aspect of channel network and contributing ground slopes. The methodologies adopted for computation of Geomorphologic parameters are follows:

- Stream order and mean stream length
- Stream length, stream length ratio, length of over land flow and drainage texture (Horton, 1945)
- Bifurcation ratio, elongation ratio and relief ratio (Schumn, 1956)
- Mean bifurcation ratio (Strahler, 1957)
- Relative relief (Melton, 1957)
- Drainage density, stream frequency and form factor (Horton, 1932)
- Circulatory ratio (Miller, 1953)
- Ruggedness number (Strahler, 1958).

Drainage area:

The drainage area 'A' is the probably the single most important watershed characteristic for hydrologic design. It reflects the volume of water that can be generated from rainfall. It is common in hydrologic design to assume a constant depth of rainfall occurring uniformly over the watershed. Under this assumption, the volume of water available for runoff would be the product of rainfall depth and the drainage area.

Ordering of channel network:

The channel network may be ordered according to the Strahler's scheme (Strahler, 1957) as per the following rules:

Channels that originate at a source (un-branch is at the starting point) are termed as first order channels.

When two channels of order 'j' join, a channel of order 'j+1' is formed.

When two channels of different order join, the resulting channel at the downstream of the junction retains the higher order of the two joining channels.

The order of the basin is the same as that of the highest order channel. Once the basin is ordered, the basin morphological features such as the number and average length of each order channel and average area of each order sub-basin can be measured from the map. Subsequently, the geomorphological laws can be used to estimate the morphological parameters of the basin.

Hypsometric integral :

Hypsometric curves are plotted between two ratios, namely the ratios of areas between the contour and the upper perimeter and the total drainage area and the ratio of contour elevation above the base and the total relief of the watershed.

The relative area and the relative height are plotted on the abscissa and the ordinate, respectively. Hypsometric curve permits the comparison and evaluation of forms of watersheds of different sizes and elevations. It expresses simply the manner in which the volume lying beneath the ground surface is distributed from base to top. The extraction of hypsometric integral a graph was plotted with relative height in ordinate and relative area in abscissa. The hypsometric integral was calculated by measuring the area under the curve.

Length of contour and drainage lines:

The length of contours and drainage lines were calculated by masking the contours and drainage lines within the watershed in the form of bitmap using the MAP program. The

Table A : Equations used to extract various Geomorphological parameters of the Arang watershed

Sr. No.	Watershed parameters	Equations used	Details of the equations
1.	Bifurcation ratio (R_b)*	$R_b = \frac{N_u}{N_{u+1}}$	N_u = number of streams of a particular order and N_{u+1} = number of streams of the next higher order
2.	Average bifurcation ratio (R_b)	$Log_{10}N_u = a - bU$ R_b = Antilogb	U = order of stream and a and b are the regression coefficients
3.	Circulatory ratio (R_c)	$R_c = \frac{\left(\sqrt{4A\pi}\right)}{L_p}$	L_p = perimeter of the watershed (km) and A = area of the watrershed (km^2)
4.	Elongation ratio (R_e)	$R_e = \left(\sqrt{4A/\pi}\right)\left(1/L_b\right)$	L_b= maximum length of the watershed (km) and A = area of the watrershed (km^2)
5.	Relief ratio (R_r)	$R_r = \frac{H}{L_b}$	H = maximum watershed relief (km) L_b= maximum length of the watershed (km)
6.	Relative relief (R_R)	$R_R = \frac{H}{L_p}$	L_p = perimeter of the watershed (km) and H = maximum watershed relief (km)
7.	Basin shape factor (S_b)	$S_b = \frac{(L_b)^2}{A}$	L_b= maximum length of the watershed (km) and A = area of the watrershed (km^2)
8.	Ruggedness number (R_N)	$R_N = \frac{H D_d}{1000}$	D_d = drainage density (km^{-1}) and H = maximum watershed relief (m)
9.	Main stream channel slope (S_c)	$S_c = \frac{H}{10 L_{ms}}$	S_c = stream channel slope (%), H_e = elevation difference between the head and tail ends of the stream (m) and L_{ms} = length of the stream (km)
10.	Average slope of the watershed (S_a)	$S_a = \frac{H L_{ca}}{A}$	A = drainage area of the watershed (km^2) and L_{ca} = average length of the contour (km)
11.	mean length of channel. ($\bar{L}_u$)	$\bar{L}_u = \frac{\sum_{i=1}^{N} Lu}{N_u}$	Lu = mean length of channel of order u N_u = total number of stream segments of order u.
12.	Stream length ratio (R_L)	$R_L = \frac{\bar{L}_u}{\bar{L}_{u-1}}$	L_u = average length of steam of order u L_{u-1} = average length of steam of next lower order.
13.	Area ratio (R_A)	$R_A = \frac{\bar{A}_u}{\bar{A}_{u-1}}$ u=1, 2, ...,Ω	Ω = order of the basin $\bar{A}_u$= average area contributing to stream order u, $\bar{A}_{u-1}$ = average area contributing to steam of next lower order
14.	Drainage density (Dd)	$Dd = \frac{Ls}{A}$	L_s = length of stream of stream segment (Km), A = basin area in km^2
15.	constant of channel maintenance (C)	$C = \frac{1}{Dd}$	Dd = drainage density.
16.	Length of overland flow (Lo)	$Lo = \frac{1}{2Dd}$	Dd = drainage density.
17.	Stream/drainage frequency (Sf)	$Sf = \frac{Nu}{A}$	Nu = total number of stream segments of order 'u' A = basin area in km^2.
18.	Form factor (Ff)	$Ef = \frac{1}{Sb}$	Sb = basin shape factor.

program "histogram image" generated the output in the form of a histogram representing the length of contours and drainage lines in pixel units (total number of pixel). Pixel unit were converted in to length unit by multiplying pixel dimension and used for further analysis. The length of contours and drainage channels were used for determination of average slope of the watershed and ruggedness number, respectively. Some other parameter used to extract varoous morphological parameters of the Arang watershed are presented in Table A.

RESULTS AND DISCUSSION

The experimental findings obtained from the present study have been discussed in following heads:

Geomorphological analysis :

Geomorphological is a science that attempts to quantify the shape of drainage basin. Various parameters were extracted from the thematic maps including watershed boundary, drainage map and digital elevation model (Plate 1 and 2). The geomorphological analysis parameters of the watershed are given in Table 1 and 2.

Table 1 : Geomorphological parameters of the Arang watershed

Order of the basin					Individual area
Order (i)	N_i	L_i	A_i	$\overline{L_i}$	A'_i
1	20	26.14	32.35	1.30	32.35
2	4	9.37	43.94	2.342	11.59
3	1	8.5668	54.50	8.56	10.59
No. of streams draining directly to streams of higher order					
Order		2		3	
1		11		9	
2		-		4	

N_i : Number of streams of order 'i'
L_i : Length of all streams of order 'i' (km)
A_i : Area of all sub-basins of order 'i' (km^2)
A'_i : Area draining directly to streams of order 'i' (km^2)

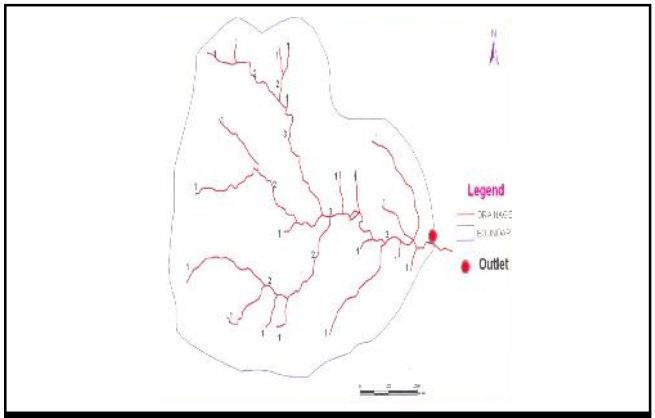

Plate 1 : Drainage map of the Arang watershed

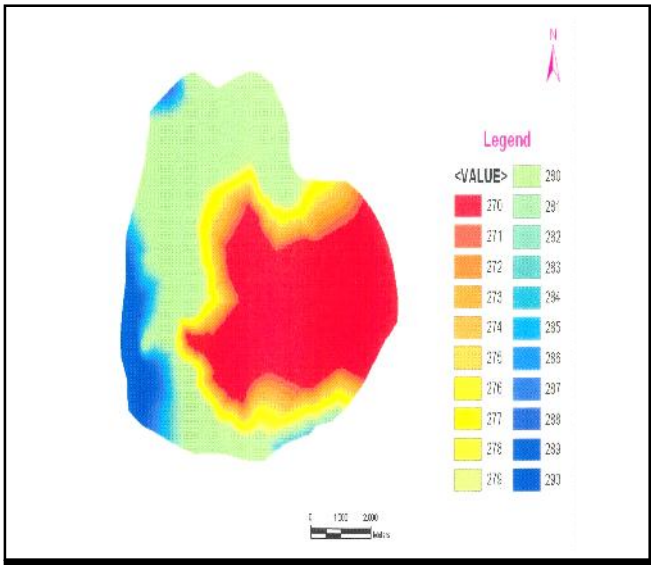

Plate 2 : Digital elevation model of the watershed

Table 2 : Values of Geomorphological parameters of the Arang watershed

Sr. No.	Watershed parameters	Value
1.	Watershed area (A,) km^2	54.50
2.	Perimeter of the watershed,(Lp) km	28.60
3.	Total length of dainage, km	44.07
4.	Length of all the streams, km	44.08
5.	Length of main stream, (Lms) km	8.56
6.	Maximum length of watershed (Lb), km	11.85
7.	Total length of all contours, (Lca) km	59.75
8.	Average contour length, km	19.91
9.	Maximum relief of the watershed, (H) m	20
10.	Area ratio (R_A)	3.5481
11.	Hypsometric integral (Hsi) km	0.998
12.	Drainage density (Dd) km/km^2	0.808
13.	Length of over land flow (Lo) km	0.618
14.	Constant of channel maintenance (C) km	1.237
15.	Average slope of the watershed (Sa)	0.015
16.	Main channel slope (Sc)	0.005
17.	Compactness coefficient (C_c)	1.093
18.	Circularity ratio (R_c)	0.9148
19.	Elongation ratio (R_e)	0.973
20.	Length ratio	2.724
21.	Bifurcation ratio (R_b)	4.461
22.	Stream frequency (Sf) km^{-2}	0.458
23.	Basin shape factor (Sb)	2.578
24.	Form factor (Ff)	0.387
25.	Drainage factor (Df)	0.701
26.	Relative relief (RR)	1.452*10-3
27.	Relative ratio (Rr)	1.687 *10-3
28.	Ruggedness number (RN)	0.016

Conclusion:

The morphological parameters like stream order, stream length, area perimeter, basin length, bifurcation ratio, circulatory ratio, elongation ratio, relief ratio, relative relief, basin shape factor, ruggedness number, average slope of the watershed and length of overland flow of the watershed etc. can be extracted using various thematic maps of the watershed and standard procedure. These parameters are indicating that topography of the watershed is flat so that the soil erosion will be less of watershed.

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