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Remote Sensing and GIS based Approach for Morphometric Analysis of Selected Watersheds in Chiplun Tehsil of Maharashtra, India

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A B S T R A C T

Geospatial technologies i.e. Remote Sensing (RS) and Geographic Information System (GIS) are found to be very essential tools for geographical and geospatial studies. RS and GIS were adopted for the determination of morphological characteristics of the Chiplun tehsil of Maharashtra, India. It was found that, there were 1362 micro watersheds in Chiplun tehsil covering an area of 1119.95 km^2. Several morphometric parameters were computed and analyzed *viz.* linear aspects such as stream order, stream number, stream length, mean stream length, stream length ratio; areal aspects such as drainage density, stream frequency, drainage texture, elongation ratio, circularity ratio, form factor, constant of channel maintenance; relief aspects such as relief, relief ratio, relative relief, ruggedness number and length of overland flow. It was concluded that, morphometric analysis of a watershed is a quantitative way of describing the characteristics of the surface form of a drainage pattern and provides important information about the region's topography and runoff.

Introduction

Remote Sensing (RS) means obtaining information about an object, area or phenomenon without coming in direct contact with it whereas, Geographical Information System (GIS) primarily deals with geographic data to be analyzed, manipulated and managed in an organized manner through computers to solve real World problems (Patra, 2015). RS technique is the convenient method for morphometric analysis as the satellite images providing a synoptic view of a large area and is very useful in the analysis of drainage basin morphometry (Rai *et al.*, 2014). The morphometric characteristics of the basin are fundamental to understand the various hydrological behavior or process (Sarma *et al.*, 2013). Various hydrological phenomena is correlated with the physiographic characteristics of a drainage basin such as size, shape, slope of the drainage area, drainage density, size and length of the contributories, etc. (Pande and Moharir, 2015). Detailed morphometric analysis of a basin is a great help in understanding the influence of drainage morphometry on landforms and their characteristics (Sreedevi, 2009). Morphometric and hypsometric analysis is widely used to assess the drainage characteristics of the river basins (Umrikar, 2016).

The fast emerging Spatial Information Technology, RS, GIS and GPS are effective tools to overcome most of the problems of land and water resources planning and management rather than conventional methods of data processing (Rai *et al.*, 2014). Over the past two decades these information has been increasingly derived from the digital representation of topography, generally called as the Digital Elevation Model (DEM). In recent years the automated determination of drainage basin parameter has been shown to be efficient, time saving and ideal application of GIS technology (Sarma *et al.*, 2013). In the present study an attempt has been made to with specified objective to analyze the morphometric characteristics of the major watersheds of Chiplun tehsil of Ratnagiri district of Maharashtra using RS and GIS.

Materials and Methods

Study area

As shown in Fig. 1, Chiplun tehsil is located between longitude $73^0$19’48” E to $73^0$45’ E and latitude $17^0$37’12” N to $17^0$13’12” N on western coast of India in southern part of the Ratnagiri district, Maharashtra, India. The total area of Chiplun tehsil is 1119.95 km^2. It receives an average annual rainfall of about 3804 mm. The average minimum and maximum temperatures are 7.5^0C and 38.5^0C, respectively. The relative humidity varies from 55% to 99%. The soil in the region is highly drainable lateritic and non-lateritic soils (Mandale, 2016).

Watershed delination

Watershed delineation plays an important role in watershed management (Singh, 2000). Arc-GIS 10.3 software is used for the purpose of watershed delineation using CartoDEM data. The shape file generated through watershed delineation of the study area is used for clipping satellite images for further processing.

Morphological characteristics

The physical properties of the watershed affect the characteristics of runoff and are of great interest in hydrologic analysis. The morphological characteristics such as stream order, drainage density, channel length, channel slope, watershed length and width, topography, geology and or soil characteristics, climate, vegetation and land use are all important to our understanding the physical processes of the watershed (Singh, 2000).

Morphological characterization is the systematic description of watershed geometry. Geometry of drainage basin and its stream channel system required the following measurements (Singh, 2000):

1. Linear aspect of drainage network

2. Areal aspect of drainage basin

3. Relief aspect of channel network and contributing ground slopes

The morphometric parameters of the watershed, their symbol used and formulae adopted are shown in Table 1.

Results and Discussion

It was found that there were 1362 micro-watersheds located in Chiplun tehsil derived from DEM, out of which, five micro-watersheds were having an area above 50 km^2. Fig. 2 shows all the micro-watersheds in the study area. As these are major micro-watersheds in Chiplun tehsil, the morphological characteristics of these watersheds were determined. These watersheds had well developed drainage network up to 5^{th} stream order with the total area of 1119.95 km^2.

Linear aspects of drainage network

Stream order (u)

Application of this ordering procedure through GIS showed that the drainage network of the study area was upto 5^{th} order basin.

Stream number (N_u)

From Table 2, it was observed that the total numbers of streams of 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} order for watershed 1 were 145, 32, 8, 2 and 1, respectively. It was observed that the total number of streams gradually decreased as the stream order increased. Fig. 3, 4, 5, 6 and 7 shows the drainage map of watershed 1, 2, 3, 4 and 5, respectively.

Bifurcation ratio (R_b)

From Table 2, it was observed that the mean bifurcation ratio (R_b) for watershed 1 was found to be 3.63. Similarly, the mean bifurcation ratio of watershed 2, 3, 4 and 5 was 3.43, 3.55, 8.5 and 3.7, respectively. The value of mean R_b of watershed 1, 2, 3 and 5 indicates geological structures do not disturb the drainage pattern. The value of R_b was 8.5 for watershed 4 indicates that geologic structures do not exercise a dominant influence on the drainage pattern (Chow, 1964).

Mean stream length (L_u)

From Table 2, it was observed that the mean stream length decreases with increase in order of stream. This may be due to the geomorphologic, lithological and structural control and contrast (Strahler, 1964).

Stream length ratio (R_L)

From Table 2, it was observed that the average stream length ratio for watersheds 1 was found to be 0.55. Similarly the average stream length ratio for watersheds 2, 3, 4 and 5 was 0.54, 0.40, 0.68 and 0.51, respectively. The stream length ratio has an important relationship with surface flow discharge and erosion stage of basin. It may be controlled by structure and streams having limited length (Sreedevi *et al.,* 2009). Thus, these watersheds are prone to erosion.

Areal aspects of drainage network

Form factor (R_f)

From Table 3, it was observed that the form factor for watershed 1, 2, 3, 4 and 5 were 0.82, 0.43, 0.44, 0.24 and 0.69, respectively. The shape of watershed is identified by this ratio. R_f values varied from 0.24 to 0.82. This value in all watersheds indicates that they are elongated to sub-circular in shape. The elongated basin indicates that the basin has a flatter peak of flow. The index of form factor shows the inverse relationship with the square of the axial length and a direct relationship with peak discharge (Horton, 1945). Thus, soil conservation structures need to be constructed as a safeguard against peak floods.

Circulatory ratio (R_c)

From Table 3, it was observed that the circulatory ratio for watersheds 1, 2, 3, 4 and 5 were 0.41, 0.32, 0.43, 0.29 and 0.69, respectively. The circulatory ratio ranged between 0.4 to 0.6 for watershed 1, 3 and 5 which indicates strongly elongated and highly permeable homogenous geologic materials as shown in Fig. 2, Fig. 4 and Fig. 6, respectively. The values for watershed 2 and 4 were 0.32 and 0.29, respectively which indicates the tendency of small drainage basin in homogeneous geologic materials to preserve geometrical similarity as shown in Fig. 3 and Fig. 5, respectively. The ratio is more influenced by length, frequency and gradient of various orders rather than slope conditions and drainage pattern of the basin (Miller, 1953).

Elongation ratio (R_e)

From Table 3, it was observed that elongation ratio for watersheds 1, 2, 3, 4 and 5 were 1.59, 1.31, 1.15, 1.03 and 1.13, respectively. The value of elongation ratio of 1.59 and 1.31 were observed for watershed 1 and 2, respectively which indicates high infiltration capacity and low run off conditions. The watersheds 3, 4 and 5 had low elongation ratio values of 1.15, 1.03 and 1.13, respectively, indicates that they are susceptible to high erosion and sedimentation load. Also it indicates strong relief and steep ground slope (Rai *et al.*, 2014).

Drainage Density (D_d)

From Table 3, it was observed that the drainage density for watersheds 1, 2, 3, 4 and 5 were 0.94, 1.02, 1.01, 1.01 and 1.02 km^{-1}, respectively. The drainage density indicates the closeness of spacing of channels and thus stream channel for whole basin. The drainage density for all 5 watersheds indicates weak and impermeable subsurface materials, good vegetation and high relief (Manjare *et al.*, 2014).

Constant of channel maintenance (C)

From Table 3, it was observed that the values of constant of channel maintenance for watersheds 1, 2, 3, 4 and 5 were 1.06, 0.98, 0.99, 0.99 and 0.98 $km^2 km^{-1}$, respectively. All the 5 watersheds had higher values for this parameter which indicates low value of drainage density (Schumn, 1956).

Drainage texture (T)

From Table 3, it was observed that drainage texture for watershed 1, 2, 3, 4 and 5 were 2.03, 1.77, 1.96, 1.2 and 1.57 km^{-1}, respectively. This parameter shows the relative spacing of drainage network. Drainage texture less than 2 indicates very coarse, between 2 and 4 as coarse, between 4 and 6 as moderate, between 6 and 8 as fine and above 8 as very fine drainage texture (Smith, 1950). Thus, watershed 1 had coarse texture and watersheds 2, 3, 4 and 5 had very coarse texture.

Relief aspects of drainage network

Relief (H)

From Table 4, it was observed that the relief was same for all five watersheds of 0.05 km. Basin relief is an important factor in understanding the denudational characteristics of the basin (Sreedevi *et al.*, 2009).

Maximum relief

From Table 4, it was observed that maximum relief for watersheds 1, 2, 3, 4, and 5 were 0.95, 0.05, 0.3, 0.15 and 0.85 km, respectively.

Relief ratio (R_n)

From Table 4, it was observed that relief ratio for watersheds 1, 2, 3, 4 and 5 were 0.05, 0.016, 0.05, 0.017 and 0.016, respectively. High value of relief ratio 0.05 for watersheds 1 and 3 indicates hill regions, high relief and steep slopes. Low values of 0.016, 0.017 and 0.016 for watersheds 2, 4 and 5, respectively indicates valley (Sreedevi *et al.*, 2009).

Relative relief (R_{hp})

From Table 4, it was observed that the relative relief for watershed 1, 2, 3, 4 and 5 were 0.054, 0.055, 0.072, 0.082 and 0.13%, respectively.

Ruggedness number

From Table 4, it was observed that ruggedness number for watershed 1, 2, 3, 4 and 5 were 0.047, 0.051, 0.05, 0.05 and 0.051, respectively. This value of ruggedness number occurs when both variables are large and slope is not only steep but long (Strahler, 1956).

Geometric number

From Table 4, it was observed that geometric number for watersheds 1, 2, 3, 4 and 5 were 0.18, 0.57, 0.54, 0.49 and 0.26, respectively.

Ground slope

From Table 4, it was observed that the value of ground slope for watersheds 1, 2, 3, 4 and 5 were 0-26, 0-8.9, 0-9.2, 0-10.3 and 0-19.3%, respectively. An understanding of slope distribution is essential as a slope map provides data for planning, settlement, mechanization of agriculture, etc. (Sreedevi *et al.*, 2009). Maximum slope of 0-26% was observed for watershed 1 as shown in Fig. 8 which indicates direction of channel reaching downwards on the ground surface. Also higher slope gradient results in rapid runoff with potential soil loss or erosion (Pande and Moharir, 2015). Slope map for watersheds 2, 3, 4 and 5 are shown in Fig. 9, Fig. 10, Fig. 11 and Fig. 12, respectively.

Table.1 Morphometric parameters

Morphometric Parameters	Symbol	Formulae	Particulars	Reference
Linear aspect of drainage network				
Stream order	u	Hierarchical Rank	u = stream order	Strahler, 1964
Stream number	N_u	-	N_u = Number of stream of order u	Strahler, 1964
Bifurcation ratio	R_b	$R_b = \frac{N_u}{N_{u+1}}$	R_b = bifurcation ratio N_u = number of streams of order u N_{u+1} = number of streams of order u+1	Schumm, 1956
Mean stream length	$\bar{L}_u$	$\bar{L}_u = \frac{\sum_{i=1}^{n} L_u}{N_u}$	$\bar{L}_u$ = mean length of channel of order u L_u = total length of stream segments of order u	Hortan, 1945

Stream length ratio	R_L	$R_L = \frac{\bar{L}_u}{\bar{L}_{u-1}}$	$\bar{L}_{u-1}$ = mean length of stream of next lower order	Hortan, 1945
Areal aspect of drainage basin				
Form factor	R_f	$R_f = \frac{A_u}{L_b^2}$	A_u = basin area L_b = basin length	Hortan, 1945
Circulatory ratio	R_c	$R_C = \frac{A_U}{A_C}$	A_C = area of circle	Miller, 1953
Elongation ratio	R_l	$R_l = \frac{D_C}{L_{bm}}$	D_c = diameter of circle L_{bm} = maximum basin length	Schumm, 1956
Drainage density	D_d	$D_d = \frac{L}{A}$	L = Total length of all stream segments A = watershed area	Hortan, 1945
Constant of channel maintenance	C	$C = \frac{1}{D_d}$	D_d = drainage density	Hortan, 1945
Stream frequency	F	$T = \frac{N}{P}$	N = Total number of streams of all order P = Basin perimeter	Hortan, 1945
Drainage texture	T	$R_f = \frac{A_u}{L_b^2}$	A_u = basin area L_b = basin length	Hortan, 1945
Relief aspect of channel network				
Relief	h	-	H= relief	Schumn, 1956
Maximum relief	H	$R_n = \frac{H}{L_h}$	L_h = horizontal distance	Schumm, 956
Relief ratio	R_n	$R_{hp} = \frac{H}{P} x 100$	H = basin relief P = perimeter of basin	Schumn,1956
Relative relief	R_{hp}	$HD = H x D_d$	H = basin relief D_d = drainage density	Schumn,1956
Ruggedness number	HD	$L_g = \frac{1}{2D_d}$	D_d = drainage density	Strahler, 1964
Geometric number	GN	$R_n = \frac{H}{L_h}$	H= relief	Schumn, 1956
Length of overland flow	L_g	$R_{hp} = \frac{H}{P} x 100$	L_h = horizontal distance	Hortan, 1945

Table.2 Linear aspects of drainage network

Morphological characteristics	Watershed 1	Watershed 2	Watershed 3	Watershed 4	Watershed 5
Area (km^2)	280.62	205.23	162.98	83.05	82.50
Perimeter (km)	92.54	90.19	69.36	60.52	38.74
Length of Basin (km)	18.47	21.94	19.20	18.74	10.95
Stream Order					
I	145	122	110	60	46
II	32	27	18	12	10
III	8	7	5	1	4
IV	2	3	2	-	1
V	1	1	1	-	-
Total	188	160	136	73	61
Bifurcation Ratio					
R_{b1}	4.53	4.52	6.11	5	4.6
R_{b2}	4	3.86	3.6	12	2.5
R_{b3}	4	2.33	2.5	-	4
R_{b4}	2	3	2	-	-
Average	3.63	3.43	3.55	8.5	3.7
Stream Length (km)					
L_{u1}	132.73	108.32	85.55	43.77	42.28
L_{u2}	68.47	52.55	41.54	21.55	21.58
L_{u3}	27.78	24.00	30.23	18.49	16.22
L_{u4}	33.44	16.61	7.26	-	4.42
L_{u5}	2.11	8.61	1.07	-	-
Total	264.53	210.08	165.64	83.81	84.5
Mean Stream Length (km)					
$\overline{L_{u1}}$	0.92	0.89	0.78	0.73	0.92
$\overline{L_{u2}}$	2.14	1.95	2.31	1.80	2.16
$\overline{L_{u3}}$	3.47	3.43	6.05	18.49	4.06
$\overline{L_{u4}}$	16.72	5.54	3.63	-	4.42
$\overline{L_{u5}}$	2.11	8.61	1.07	-	-
Total	25.36	20.42	13.84	21.02	11.56
Stream Length Ratio					
R_{L1}	0.52	0.49	0.48	0.49	0.51
R_{L2}	0.41	0.46	0.73	0.86	0.75
R_{L3}	1.20	0.69	0.24	-	0.27
R_{L4}	0.06	0.52	0.15	-	-
Average	0.55	0.54	0.40	0.68	0.51

Table.3 Areal aspects of drainage network

Areal Aspects	Watershed 1	Watershed 2	Watershed 3	Watershed 4	Watershed 5
Basin Area (km^2)	280.62	205.23	162.98	83.05	82.50
Form Factor	0.82	0.43	0.44	0.24	0.69
Circulatory Ratio	0.41	0.32	0.43	0.29	0.69
Elongation Ratio	1.59	1.31	1.15	1.03	1.13
Drainage Density (km^{-1})	0.94	1.02	1.01	1.01	1.02
Constant of Channel Maintenance (km^2 km^{-1})	1.06	0.98	0.99	0.99	0. 98
Drainage Texture (km^{-1})	2.03	1.77	1.96	1.2	1.57

Table.4 Relief aspects of drainage network

Relief Aspects	Watershed 1	Watershed 2	Watershed 3	Watershed 4	Watershed 5
Relief (km)	0.05	0.05	0.05	0.05	0.05
Maximum Relief (km)	0.95	0.05	0.3	0.15	0.85
Relief Ratio	0.05	0.016	0.05	0.017	0.016
Relative Relief (%)	0.054	0.055	0.072	0.082	0.13
Ruggedness number	0.047	0.051	0.05	0.05	0.051
Geometric number	0.18	0.57	0.54	0.49	0.26
Ground Slope (%)	0-26	0-8.9	0-9.2	0-10.3	0-19.3
Length of overland flow (km)	0.53	0.49	0.49	0.49	0.49

Fig.1 Location map of the study area

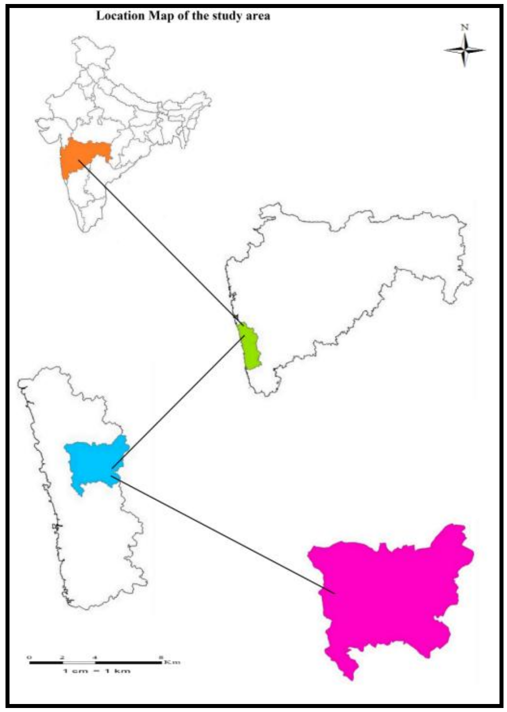


Fig.2 Micro-watersheds in Chiplun Tehsil

Fig.3 Drainage Map – Watershed 1

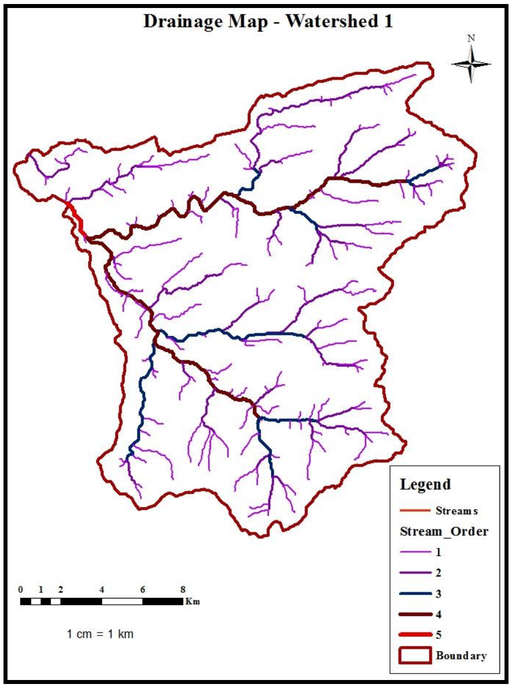


Fig.4 Drainage Map – Watershed 2

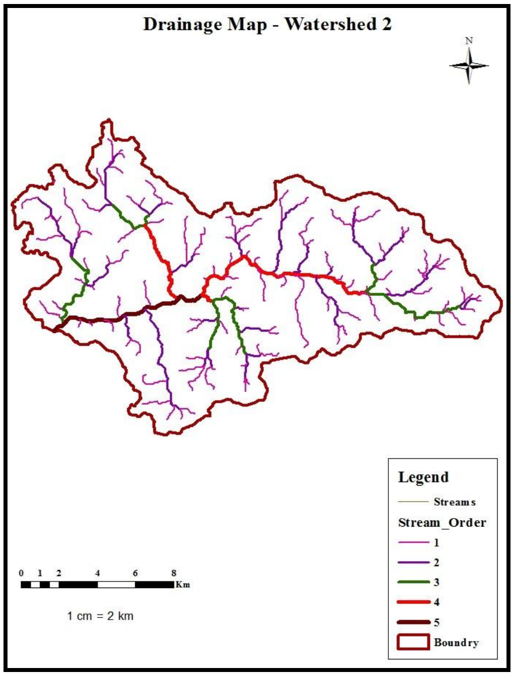


Fig.5 Drainage Map – Watershed 3

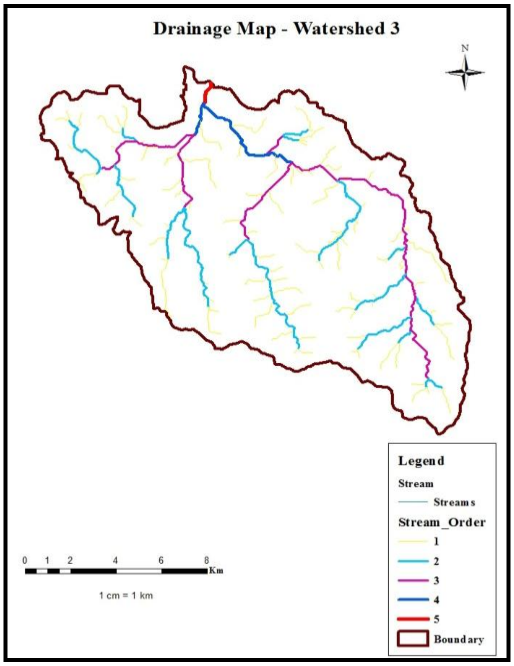


Fig.6 Drainage Map – Watershed 4

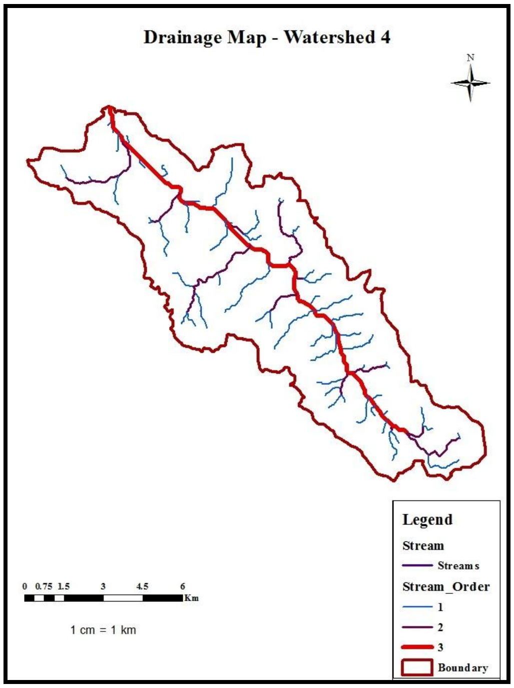


Fig.7 Drainage Map – Watershed 5

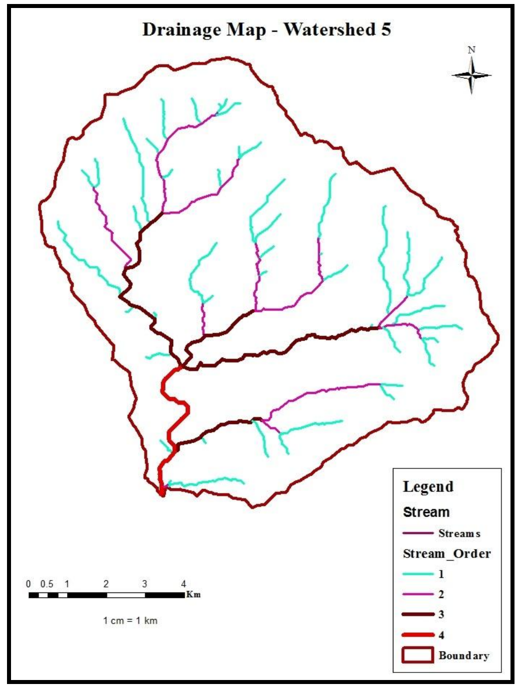


Fig.8 Slope Map – Watershed 1

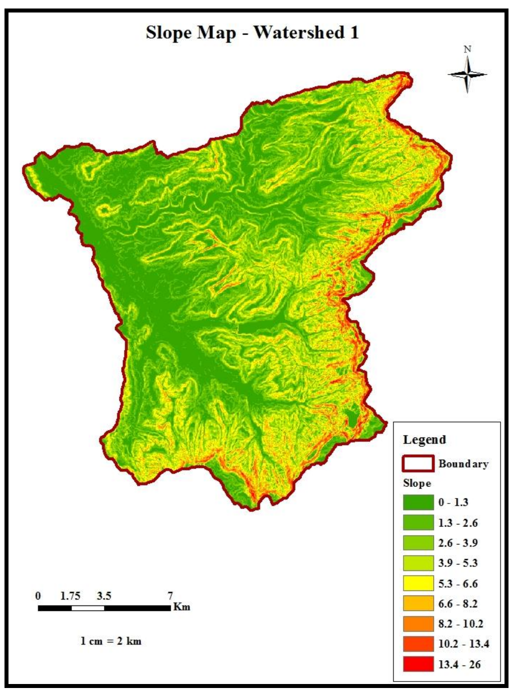


Fig.9 Slope Map – Watershed 2

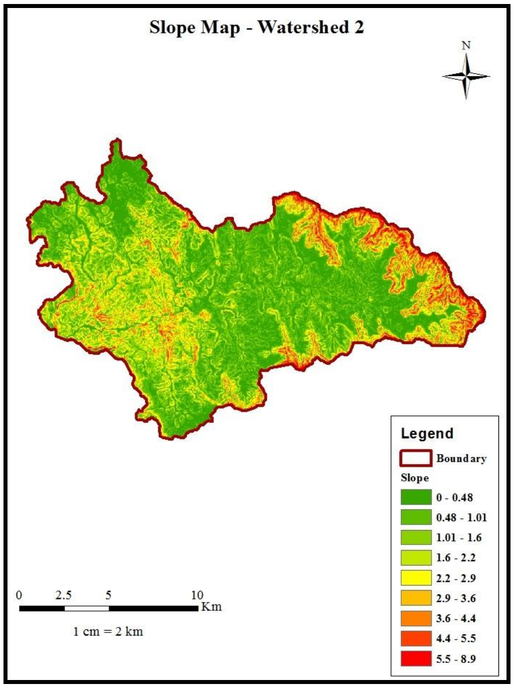


Fig.10 Slope Map – Watershed 3

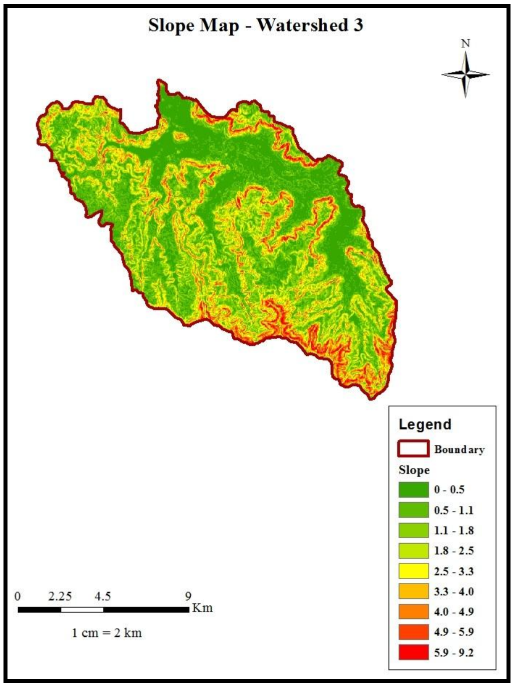


Fig.11 Slope Map – Watershed 4

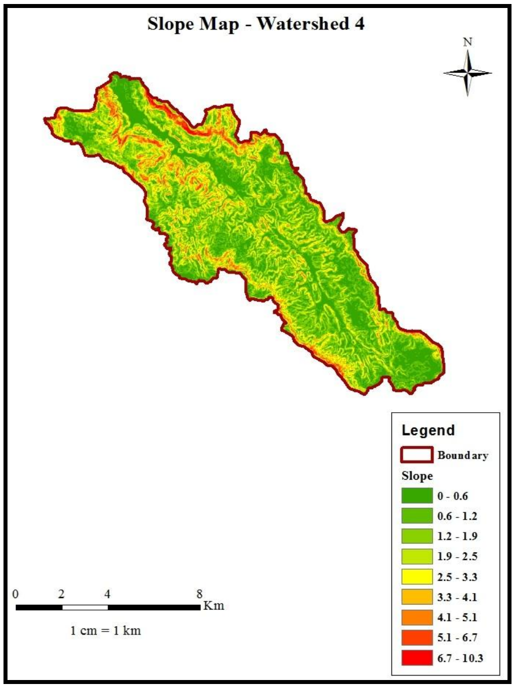
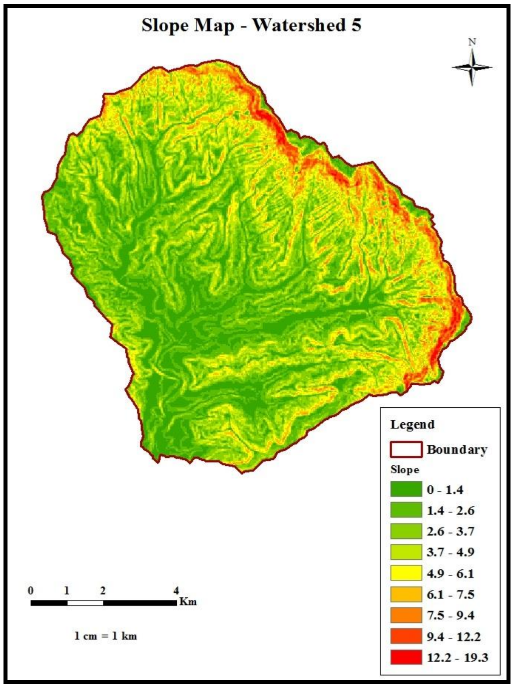


Fig.12 Slope Map – Watershed 5



Length of overland flow (L_g)

From Table 4, it was observed that the length of overland flow for watersheds 1, 2, 3, 4 and 5 were 0.53, 0.49, 0.49, 0.49 and 0.49 km, respectively. Length of overland flow is one of the most important morphometric variables which affect the hydrological and topographic development of drainage network (Kumar, 2013). The high values for this parameter indicates high surface runoff (Manjare *et al.*, 2014).

In conclusions, morphometric analysis of a watershed is a quantitative way of describing the characteristics of the surface form of a drainage pattern and provides important information about the region's topography and runoff. Higher value of bifurcation ratio indicated the watershed had elongated shape and low value indicated the circular shape. The variations in stream length ratio in the study area are due to variations in slope and topography. Form factor in all watersheds indicated that they were elongated to sub-circular in shape. The circulatory ratio ranged from 0.4 to 0.6 which indicated strongly elongated and highly permeable homogenous geologic materials. The circulatory ratio less than 0.4 indicated the tendency of small drainage basin in homogeneous geological material to preserve geometrical similarities. The high value of elongation ratio indicated high infiltration capacity and low runoff conditions whereas low elongation ratio values indicated that they were susceptible to high erosion and sedimentation load. Low value of drainage density indicated low permeability, moderate to steep slope and high surface runoff. It was observed that the relief was same for all five watersheds of 0.05 km. High value of relief ratio indicated hill regions, high relief and steep slopes whereas low values indicated valley. The high values of length of overland flow indicated high surface runoff and low values had low surface runoff.

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