Comparative Study of Morphometric Parameters Derived from Topographic Maps and ASTER DEM

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1 Introduction

Geographic Information System and Digital Image Processing have rapidly emerged as an important tool in the treatment of geo and image information for scientific, commercial and operational applications. In remote sensing DEMs are used with GIS to correct images and to retrieve thematic information with respect to sensor geometry and local relief to produce geocoded product. Topographical information in DEMs can be represented and stored in three different forms namely as: (i) grid, (ii) triangulated irregular network (TIN) and (iii) contour-line models (Weibel and Heller, 1991; Tarboton, 1997; Richard, 2004). Grid DEMs have commonly used data source for digital terrain analysis because of its simple data structure and compatibility with other digitally produced data (Holmgren, 1994; Gao, 1998; Wise, 2000; Li, 2000) has been used in the present work. The automated extraction of topographic parameters from digital elevation models (DEMs) helps to generate physiographic information required in watershed models such as configuration of the channel network, location of drainage divides, channel length and slope, sub-watershed geometric properties and a variety of topographic parameters (Tribe, 1992, Martz and Garbrecht, 1998).

The surface drainage pattern characteristics of various basins have been studied using conventional methods given by Horton, 1945, Strahler, 1964. The present work is an integrated approach, using digital topography, remotely sensed data and GIS for the comparative morphometric analysis of Sitla Rao watershed. Remote sensing and GIS techniques have been used effectively for updating and monitoring the spatial analysis of the morphometric and parametric databases of the study area.

2 Study Area

The study area, Sitla Rao (Fig.1) is situated in the western part of Dehradun district, Uttrakhand in the Lesser Himalayas. The geographical dimension extends from 30°24'00" to 30°30'00" N latitude and 77°45'33" to 77°57'00" E longitude. The area under investigation lies in the foothill zone of Himalaya and occupies 183 km^2 area within the Doon valley. The river under investigation is a seasonal river which is a tributary of Asan River that occupies the central part of the valley.

3 Physiography

Physiographically the area is characterized by rugged mountain terrain with deep narrow valleys, higher peaks and ridges along with erosional surfaces, river terraces, hill side slope, upper piedmont, middle piedmont and lower piedmont. The study area has southwest slope. The slope of the terrain varies from moderate sloping (<15%) in the downhill part to steep sloping (45%) in the upper part (Saran et al., 2009).

4 Geology

Dehradun valley is an intermontane valley lies between the Lesser Himalaya in the north and the Siwalik in the south. The Geology of the Doon Valley and its surrounding was studied by Auden (1934) and Rupke (1974) whereas geology of the area had been mapped by Jha (1995). Geologically the entire Doon valley can be divided into three regions viz; the Lesser Himalaya, the Siwalik and the Doon Gravel. The study area occupies the rock units belonging to the lesser Himalaya, bounded by MCT in the north and MBT in south by thickly bedded multistoried sandstone and characterized by mudstone/siltstone of early Paleozoic to lower Paleozoic age.

5 Drainage

Doon valley is bounded by two perennial rivers Yamuna and Ganga which drains the entire area with its tributaries as well as NW flowing Asan and SE flowing Suswa-Song respectively. The drainage network is dense and drainage pattern tends to be structurally controlled by bed rock geology and is dendritic to sub-dendritic, whereas in homogenous lithology drainage pattern is parallel.

6 Methodology

Morphometric parameters of drainage with respect to linear, areal and relief were evaluated by the established mathematical equations (Table 1). These evaluated parameters were applied to two types of drainage networks. The first drainage network was created from topographic map in GIS environment. Survey of India topographic map No. 53 F/15 at 1:50,000 scale was registered using UTM projection plane (Zone 43N), with the help of Georeferencing Tool 1.0.0.0 and Geographic Translator 2.3. The second drainage network was extracted from a DEM, generated from the contours of 15-m intervals, using SAGA 2.0 software.

On the basis of the drainage order, both drainage networks were classified into different orders using the Strahler method (1952) which designates a segment with no tributaries as a first-order stream. Two first-order segments join to form a second order segment: two second-order segments join to form a third-order segment and so on. Stream orders of drainage networks derived from topographic maps were entered manually whilst those derived from DEM were assigned automatically in GIS.

7 Result and Discussion

7.1 Linear Aspects

The linear aspects include stream order, stream length, mean stream length stream length ratio and bifurcation ratio and the results of the analysis are given in Table 2 and 3 and discussed below.

Stream Segments and Stream Order (Nu)

This is a section of stream channel between two channel junctions or "fingertip" tributaries between a junction and the upstream termination of a channel. One of the first attributes to be quantified in morphometric analysis is the hierarchy of stream segments according to an ordering classification system.

In the drainage map of the study area (Fig.2 a and b) stream segments in each order were counted and presented in the Table 2 and 3. It is observed that the numbers of stream segments of any given order are fewer than for the next lower order but more numerous than for the next higher order, verify the Horton's Law of stream number (1945) that the number of stream segments of each order forms an inverse geometric sequence with order number. In Jagatpur and Abdullahpur micro-watersheds, second order stream joins to form one third order stream and no fourth order stream is found in these micro-watersheds, unlike other micro-watersheds calculated from the ASTER data. This shows that there is some geological factor which prevents to join lower order stream to form higher order stream.

Bifurcation Ratio (Rb)

It is the ratio of the number of stream of a given order to the number of stream of next higher order (Schumm, 1956). Horton (1945) considered it as or index of relief and dissection and suggested that the bifurcation ratios characteristically range between 3.0 and 5.0 for watersheds in which geology is reasonably homogeneous or geological structure do not disturb the drainage pattern. The present study show that Rb values in the study area ranges between 3.16 and 6.14 which are slightly higher than the range mentioned above clearly indicates the possibilities of geologic control over drainage pattern. Semi-log plots of stream order vs stream number (Fig.3 a and b) have been drawn and a straight line was fitted through these points. The slope of these lines gives the bifurcation ratio.

The lower values of Rb are characteristics of the micro-watersheds which have suffered less structural disturbances (Strahler, 1964) and the drainage patterns have not been distorted because of structural disturbances. Further low Rb values in the present study indicate area with uniform surficial materials where geology is reasonably homogeneous. High Rb values indicate structural control of drainage ways (folded-valley and ridge regions; faults) and also signify streams that have a higher average flood potential because numerous tributary segments drain into relatively few trunk transporting stream segments. Values obtained from ASTER data are higher as compared to the toposheet data, gives a better idea about the geological disturbance taken place in this small watershed of Himalaya.

Stream Length (Lu) and Stream Length Ratio (Rl)

It is the length of stream of various orders from their mouth to drainage divide. The stream length is computed following the law proposed by Horton (1945). The total length of stream segment is maximum in first order and decreases as the stream order increases. This trend is followed in all the micro-watersheds of the area of interest. However, stream lengths measured from toposheet for Rudarpur micro-watershed do not follow this trend. This may possibly be due to flow of stream from high altitude, change in rock type, moderately steep slope and probable uplift across the micro-watershed (Singh and Singh, 1997, Vittala *et al.,* 2004, Chopra *et al*., 2005)

Mean Stream Length (Lsm): Mean stream length is calculated by dividing the total stream length of a particular order and number of stream of segment of that order. Mean stream length of a stream channel segment is a dimensional property, reveals the characteristic size of drainage network component and contribute basin surface (Strahler, 1964). The mean stream length values obtained from toposheet and ASTER are variable. Toposheet values obtained from Rudarpur, Jagatpur and Abdullahpur micro- watersheds show variation in second and third order stream, while the values obtained from ASTER data show variation in third and fourth order streams in Chhorba micro-watershed and second and third order stream segment in Abdullahpur micro- watershed. The variation in mean stream length of Abdullahpur micro- watershed from both the data clearly indicates variation in topographic elevation and slope.

Stream Length Ratio (SLR)

The stream length ratio is defined as the ratio of the mean stream length of a given order to the mean stream length of next lower order. From Table 3 it is noted that Lsm is quite variable in both the data set. This may possibly be due to variation in slope and topography indicating the late youth stage of geomorphic development of the stream in the study area (Singh and Singh, 1997, Vitlala, *et al*., 2004). Furthermore, high values of stream length ratio obtained from ASTER data in almost all the micro-watersheds, indicates their upstream location where the rocks are highly competent and impermeable.

7.2 Areal Aspects

The areal aspects include basin area, basin shape, drainage density, drainage texture, stream frequency, form factor, circularity ratio, elongation ratio and length of overland flow. The results are given in Table 4 and 5 and discussed as:

Basin Area

A drainage basin is an area defined by a topographic boundary that diverts all runoff to a single outlet. The topographic boundary that separates runoff between two basins is the drainage divide. It may also be defined as the area which is drained by stream or a system of streams in such a way that all stream flow originating within the basin parameter discharge through a single outlet.

The widespread availability of elevation data in digital format has bolstered the development of automated tools that can be used to delineate drainage basin and their associated stream network. Total area of the Sitla Rao watershed is 183 km^2. Among the micro-watershed maximum drainage area is covered by the Rudarpur micro-watershed whereas Abdullahpur micro-watershed occupies minimum drainage area (Fig.2 a and b).

Basin Shape (Bs)

The basin shape is defined as outline form of a drainage basin, as it is projected upon the horizontal datum plane of a map. The shape of the basin is a very important factor in determining discharge characteristics of streams and may considerably affect stream flow hydrograph and peak flow. Horton (1932) described the outline of a normal drainage basin as a pear shape ovoid. There are various parameters which are used to define the shape of the basin include Elongation Ratio (Re), Form Factor (Rf) and Circularity Ratio (Rc) and are same for toposheet and ASTER as the shape of the basin does not depend upon the resolution. These parameters are discussed below and graphically presented in Fig.4.

a) Elongation Ratio (Re)

Schumm, (1956) defined elongation ratio as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. The Re remains between 0.6 and 1.0 over wide variety of climatic and geographical types. Value close to 1 is typical for a very low relief region, whereas the values in the range of 0.6 to 0.8 are generally associated with strong relief and steep ground slope.

The elongation ratio in the study area varies from 0.46 to 0.64. The variation of the elongation ratio of the micro-watersheds is possibly due to guided effect of thrusting and faulting. Lower values in Dobri, Chandpur and Jagatpur micro-watersheds indicate elongated shape and tectonic control on the stream development. Although all the values suggest elongated shape of all the micro-watersheds except Chhorba micro-watershed which is less elongated.

b) Circularity Ratio (Rc)

Miller (1953) defined circulatory ratio as the ratio of basin area (Au) to the area of a circle (Ac), having the same perimeter as the basin. The circulatory ratio is dimensionless and expresses the degree of circularity of the basin.

In the present study, Rc values ranges from 0.34 to 0.68 where Chhorba micro-watershed show highest value (0.68) and that next higher value (0.62) obtained in Rudarpur micro- watershed, clearly indicates homogenous geological material in these areas. The least value of 0.34 of Dobri micro-watershed indicates that the area is characterized by high to moderate relief and drainage is structurally controlled.

c) Form Factor (Rf)

Form factor is a quantitative expression of drainage basin outline as given by Horton (1932) through form factor, which is defined as the ratio of basin area to the square of basin length. From Table 4 it is observed that the Rf varies between 0.14 -0.30 in all the six micro-watersheds.

d) Drainage Density (Dd)

Drainage density is an important indicator of the linear scale of landform element in stream eroded topography, introduced by Horton (1932) and define as a total length of streams of all order per drainage area and may be an expression of the closeness of spacing of channels. High drainage densities usually reduce the discharge in any single stream, more evenly distributing runoff and speeding runoff into secondary and tertiary streams. In areas of low drainage density, intense rainfall events are more likely to result in high discharge to a few streams and therefore a greater likelihood of "flashy" discharge and flooding in humid areas of low drainage densities, suggest resistant bedrock in humid areas and highly erodable surficial materials.

In general low drainage density is favored in regions of highly permeable subsoil material under dense vegetation cover, where relief is low and also indicative of relatively long overland flow of surface water. High drainage density is favored in regions of weak or impermeable subsurface materials, sparse vegetation and mountain relief (Chow, 1964). Langbein (1947) recognized the significance of drainage density as a factor determining the time of travel by water and suggested a drainage density varying between 0.55 and 2.09 km/km^2 in humid region with an average density of 1.03 km/km^2.

The drainage density in the study area varies between 0.68 and 1.52 km/ km^2 as incurred from toposheet and 1.13 to 1.69 km/km^2 from ASTER image indicates low drainage density. Jagatpur micro-watershed depicts minimum drainage density value obtained from ASTER data and second minimum value from toposheet (Table 5), suggests that the region has highly permeable subsurface and dense vegetation cover, whereas Dobri micro-watershed show highest drainage density and such high values are expected in a mountainous region of tropical climate with high rainfall. The density variation also suggest humid climate of the study area.

e) Stream Frequency (Fs)

Horton (1932) defines stream frequency as the number of stream segment per unit area. The present study indicates that the values of Fs range from 0.82 to 3.34 from toposheet data and 3.22 to 4.08 from ASTER data. The values from ASTER data do not show any correlation with drainage density, while the values obtained from the toposheet clearly indicate that it is possible to construct drainage basin, having the same drainage density but different stream frequency. Rudarpur and Dobri micro-watersheds have same drainage density but the values are widely variable. However both the data set gives the highest value of Fs in Dobri micro-watershed (Table 5) in the upper reaches attest the existence at resistant but dissected bed rock in the lower zone of Sitla Rao watershed. Low values are noticed in the micro-watershed developed in midland portion.

f) Infiltration Number (If)

It is expressed as the product of the drainage density and stream frequency. The higher values of the infiltration number in a watershed clearly indicate low infiltration and high runoff. The present study shows that Jagatpur micro-watershed has minimum value, obtained from ASTER data and second minimum value from toposheet; possibly due to the high infiltration in these basins, which prove the permeability of underlying material. Dobri micro-watershed has the maximum values from both the data set; clearly indicate the presence of impermeable bed-rock, which is also evident from the presence of moderately dissected structural hill in this micro-watershed.

g) Drainage Texture (Rt)

According to Horton (1945), drainage texture is the total number of stream segments of all order per perimeter. Smith (1950) has classified drainage density into five different drainage textures. The value less than 2 indicates very coarse, between 2 and 4 is related to coarse, between 4-6 is moderate, between 6-8 is fine and greater than 8 is very fine drainage texture.

Both toposheet and ASTER data obtained from Dobri micro-watershed indicates moderate drainage texture. The value obtained from toposheet in Rudarpur micro-watershed is near to moderate texture, whereas the values obtained from ASTER data suggest fine texture. Rest of the micro-watersheds show coarse drainage texture, suggesting massive and resistant bed rock in these micro-watersheds.

h) Length of Overland Flow (Lg)

Horton (1945) define length of overland flow as the length of flow path, projected to the horizontal of non channel flow from point on the drainage divide to a point on the adjacent stream channel and noted that length of overland flow is one of the most important independent variable affecting both hydrologic and physiographic development of drainage basins. This factor basically relates inversely to the average slope of the channel and is quiet synonymous with the length of sheet flow to a large degree. Dobri and Chandpur micro-watersheds showing low values of Lg as obtained using toposheet and having high drainage density as compare to the higher values obtained from ASTER in Rudarpur, Chhobra and Chandpur micro-watersheds (Table 5).

7.3 Relief Aspects

The relief aspects include maximum basin relief, relief ratio, relative relief and ruggedness number. The results of the analysis are given in Table 6 and discuss below.

Maximum Basin Relief (H)

Maximum basin relief is the elevation difference between basin mouth and the highest point on the basin perimeter. With increasing relief, steeper hillslopes, higher stream gradients and time of concentration of runoff decreases, thereby increasing flood peaks (Patton, 1988). By using the same parameters the H value for the drainage network derived from the DEM is the same as that for the drainage network derived from the topographic maps. High values of maximum basin relief indicate the gravity of water flow, low infiltration and high runoff conditions. The value of maximum basin relief for drainage basin were determined and presented in Table 6.

Relief Ratio (Rh)

Relief ratio measures the overall steepness of a drainage basin and is an indicator of the intensity of erosion process operating on slope of the basin. Schumm (1956) measured relief ratio as the ratio of maximum basin parallel to the principal drainage line. High value of relief ratio indicate steep slope and high relief, while small value may indicate the presence of basement rock, exposed in the form of small ridge and mount with lower degree of slope (GSI, 1981). The values of Rh are given in Table-6 and ranges from 0.007 (Chandpur micro-watershed) to 0.029 (Rudarpur micro-watershed) indicates high relief and steep slope in these micro-watersheds.

Relative Relief (Rhp)

This term was used by Melton (1957) and defines Relative relief (*Rhp*) as the maximum height dispersion of a terrain normalized by its perimeter. It is noted that Abdullahpur micro-watershed has got maximum relative relief and Rudarpur micro-watershed has got the minimum value. Terrains with large Rhp values are prone to erosion more extensively than those with small Rhp values.

Ruggedness Number (HD)

The product of maximum basin relief H and drainage density D is the ruggedness number where both parameters are in the same unit. When slope is not only steep but long as well, extreme high values of ruggedness number occur (Strahler, 1958). Ruggedness number suggests steepness of slope and indicates structural complexity of a terrain.

In the present study the value of ruggedness number are variable indicating variations in elevation in different micro-watersheds. The values obtained from ASTER data are high than those obtained from toposheet. However values of Dobri micro-watersheds in both the cases are on higher side indicates highest relief of the micro-watershed.

Conclusion

Comparative morphometric analysis between toposheet and ASTER imagery with respect to linear, areal and relief aspect has been done in the present work in order to understand the changes in the surface and sub-surface condition of the study area. Drainage network of the micro-watershed shows that pattern tends to be structurally controlled by bed rock geology which is also inferred from slightly higher bifurcation ratio value. Variation in stream lengths as obtain from toposheet for Rudarpur micro-watershed may be due to flowing of stream from high altitude, change in rock type, moderately steep slope and probable uplift across the micro-watershed. Variation in elongation ratio value of Abdullahpur micro- watershed indicate variation in topographic elevation and slope of this micro-watershed and also youthful stage of geomorphic development. Elongation ratio and circularity ratio suggests all the micro-watersheds are of elongated shape which indicates low runoff and flatter peak of flow. The circularity ratio of Dobri micro-watershed indicates that the area is characterized by high to moderate relief and structurally controlled drainage system. Drainage density, stream frequency and infiltration number suggest massive, resistant but resistant bed rocks in Dobri micro-watershed as expected in a mountainous region of tropical climate with high rainfall. The higher values of drainage density obtained from ASTER data suggest increase in dissection over time which may be due to anthropogenic factor. The relief ratio and ruggedness number for Dobri micro-watershed suggest high relief and steep slope in this micro-watershed. The values obtained from ASTER data are higher than that of toposheet but comparable and gives a better idea about the geological disturbance in the study area with time.

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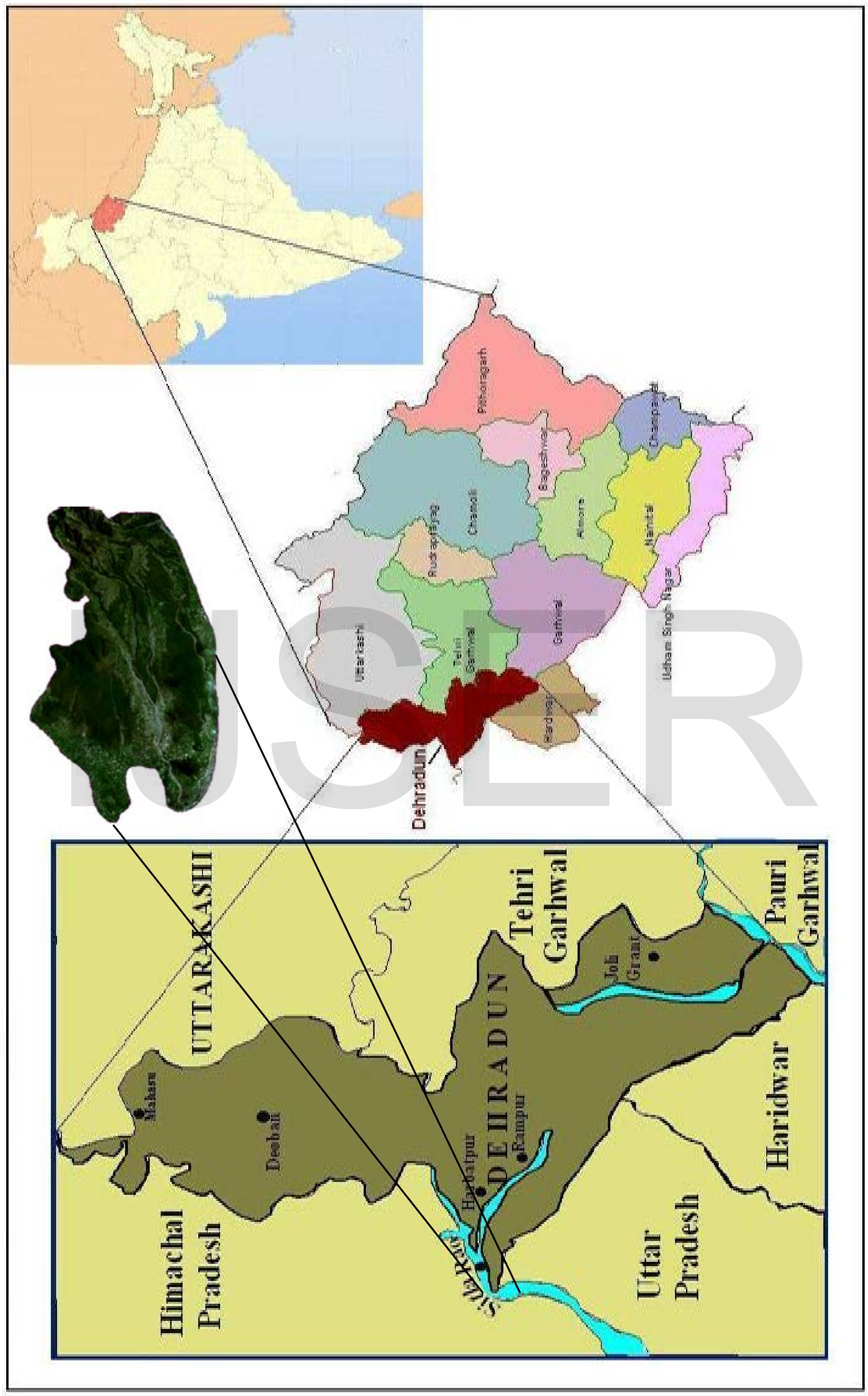

Figure 1: Location *map* of the study area

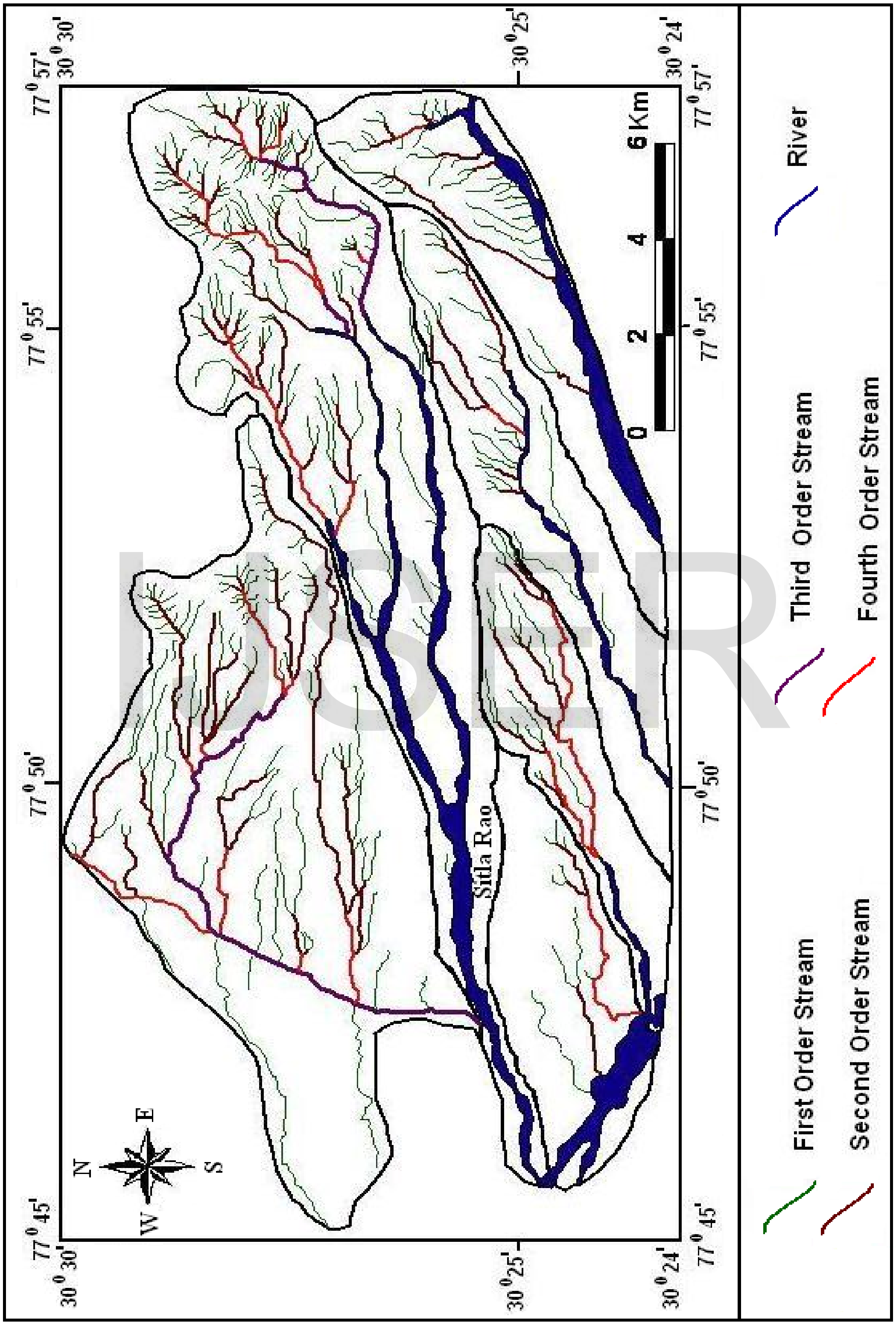

Figure 2.a: Drainage map of the study area

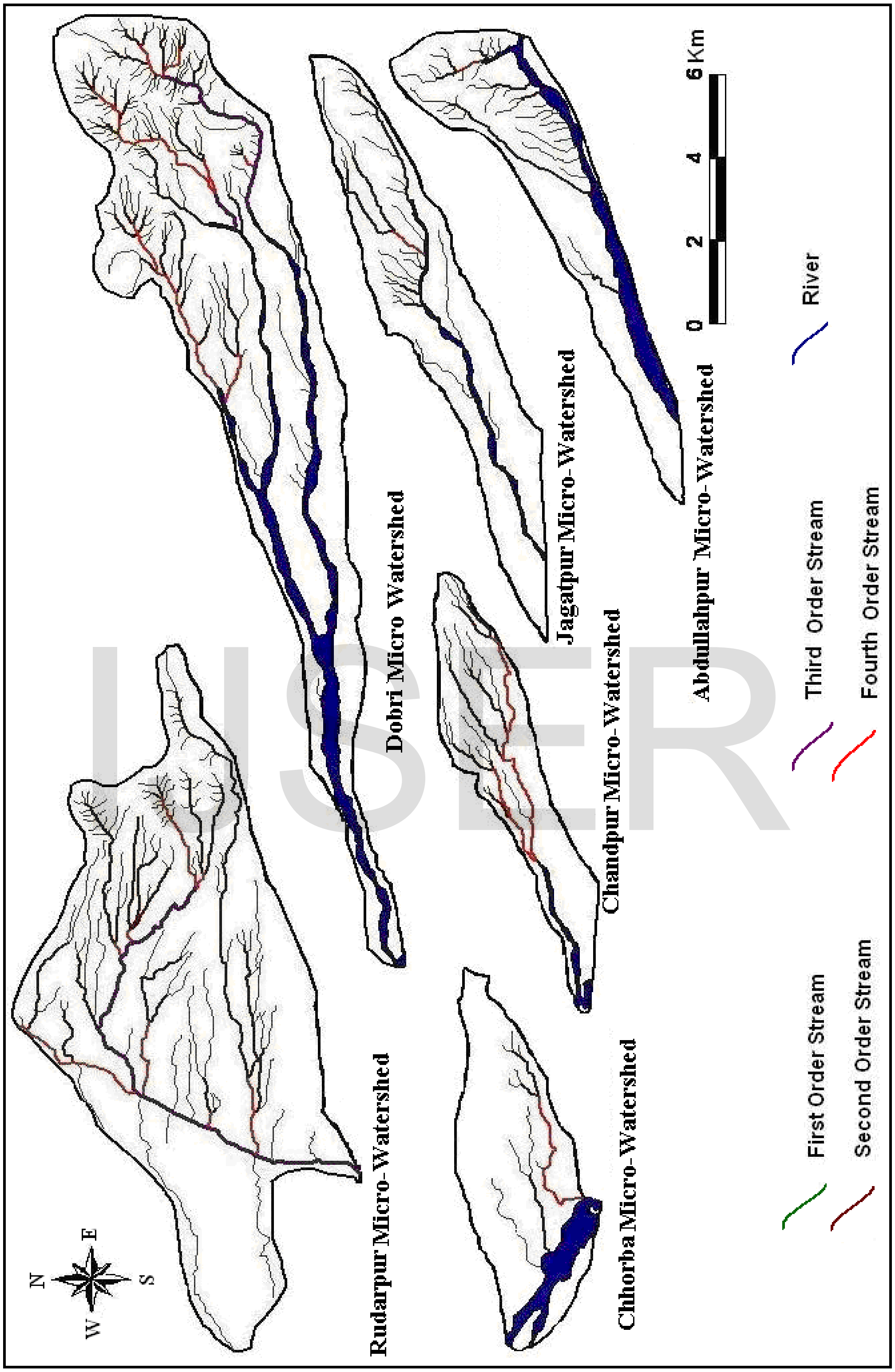

Figure 2.b: Splitted drainage map of the study area

Table 1: Methodology adopted for the computation of morphometric parameters

S.No.	Morphometric Parameters	Formula/Definition
1	Stream order	Hierarchical Rank
2	Bifurcation Ratio (Rb)	**Rb = Nu / Nu+1** Where, **Nu**=Number of stream segments present in the given order **Nu+1**= Number of segments of the next higher order
3	Mean Bifurcation Ratio (Rbm)	**Rbm** = Average of bifurcation ratios of all orders
4	Stream Length (Lu)	Length of the Stream (km)
5	Mean Stream Length (Lsm)	**Lsm = Lu / Nu,** km Where, **Lu**=Mean stream length of a given order (km) **Nu**= Number of stream segments
7	Drainage Density (D)	**D= ∑Lu /Au)** km/km^2 Where,**Lu**=Total Stream length of all orders (km) **Au**=Area of the Basin (km^2)
8	Drainage Texture(Rt)	**Rt = ∑ Nu/P** Where, **Nu**= Stream Number **P** = Perimeter (km)
9	Stream Frequency (Fs)	**Fs = ∑ Nu /Au** Where, **Nu**=Total number of streams in the basin **Au**= Basin Area (km^2)
10	Infiltration No. (If)	**If = Rt*Fs** Where, **Rt**= Drainage Texture **Fs**= Stream Frequency
11	Length of Over Land Flow (Lg)	**Lg = 1/ D×2** Km Where, **D** = Drainage density (km/km^2)
12	Form Factor (Rf)	**Rf = Au / Lb^2** Where, **Au**=Area of the Basin (km^2) **Lb**=Maximum Basin length (km)
13	Circularity Ratio (Rc)	**Rc = 4πAu/ P^2** Where, **Au**= Basin Area (km^2) **P**= Perimeter of the basin (km) **Π** = 3.14
14	Elongation Ratio (Re)	**Re= √Au/π / Lb** Where, **Au**= Area of the Basin (km^2) **Lb**=Maximum Basin length (km) **Π** = 3.14
15	Relief Ratio (Rh)	**Rh = H / Lb**max Where, **H** = Maximum basin relief (km) **Lbmax**= Maximum basin length (km)
16	Ruggedness Number (HD)	**HD= H×Dd** Where, **H=** Maximum basin relief **Dd=** Drainage density
17	Relative Relief (Rhp)	**Rhp = H× (100) / P** Where, **H** = Maximum basin relief **P** = Perimeter of the basin (km)

Table 2: Stream Number and Bifurcation Ratio

Toposheet

Stream Order	Rudarpur Micro-watershed		Dobri Micro-watershed		Chhorba Micro-watershed		Chandpur Micro-watershed		Jagatpur Micro-watershed		Abdullahpur Micro-watershed	
	Nu	**Rb**	**Nu**	**Rb**	**Nu**	**Rb**	**Nu**	**Rb**	**Nu**	**Rb**	**Nu**	**Rb**
I	99	4.95	150	4.2	10	3.33	19	2.37	23	3.83	37	5.28
II	20	2.85	35	5	3	3	7	3.5	6	6	7	7
III	7	3.5	7	3.5	1		2	2	1		1	
IV	2		2				1					

ASTER

Stream Order	Rudarpur Micro-watershed		Dobri Micro-watershed		Chhorba Micro-watershed		Chandpur Micro-watershed		Jagatpur Micro-watershed		Abdullahpur Micro-watershed	
	Nu	**Rb**	**Nu**	**Rb**	**Nu**	**Rb**	**Nu**	**Rb**	**Nu**	**Rb**	**Nu**	**Rb**
I	197	5.47	195	6.25	47	5.22	43	4.78	70	5.83	60	5
II	36	4	31	4.42	9	4.5	9	4.5	12	12	12	12
III	9	2.25	7	1.75	2	1	2	2	1		1	
IV	4		4		2		1					

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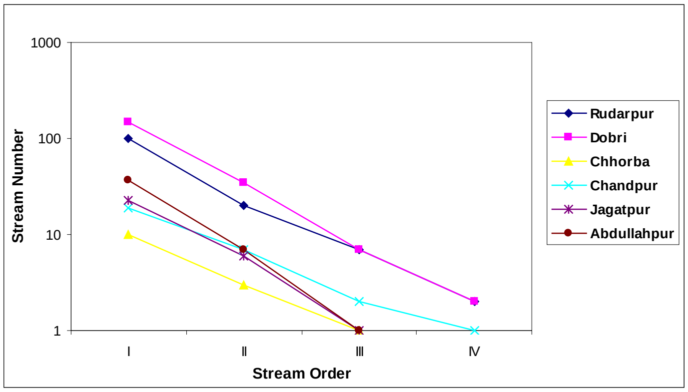


Figure 3.a: Semi log plots of Stream Order Vs Stream Number (Toposheet)

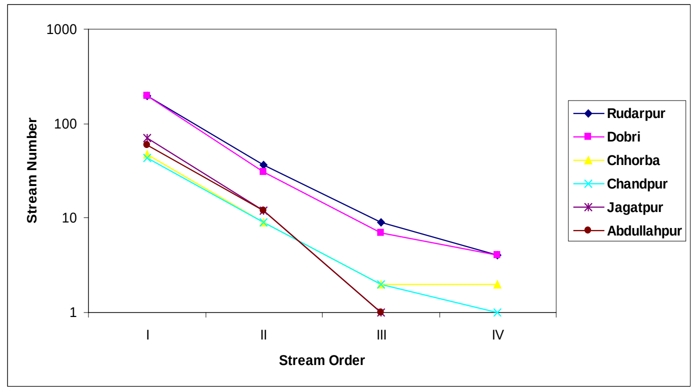


Figure 3.b: Semi log plots of Stream Order Vs Stream Number (ASTER)

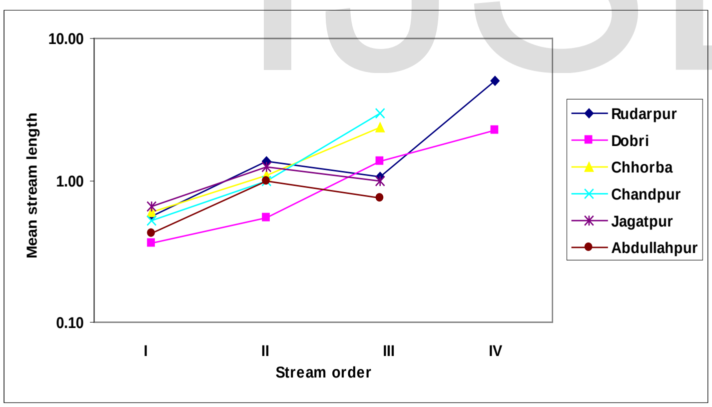


Figure 4.a: Semi-log plots of Stream Order Vs Mean Stream Length (Toposheet)

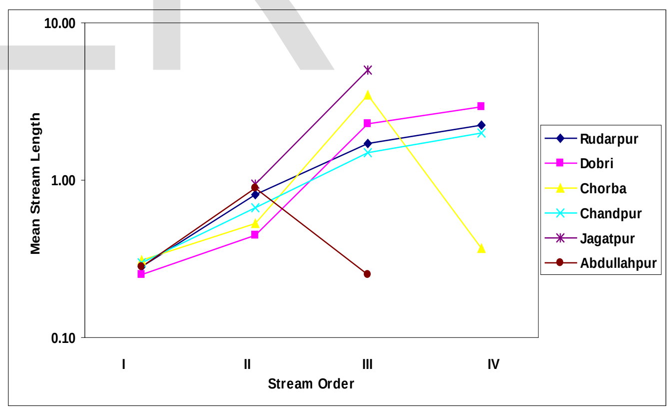


Figure 4.b: Semi-log plots of Stream Order Vs Mean Stream Length (ASTER)

Table 3: Stream Order, Stream Length and Mean Stream Length

Toposheet

Stream Order	Rudarpur micro-watershed			Dobri micro-watershed			Chhorba micro-watershed			Chandpur micro-watershed			Jagatpur micro-watershed			Abdullahpur micro-watershed		
	SL (Km)	MSL (Km)	SLR	SL (Km)	MSL (Km)	SLR	SL (Km)	MSL (Km)	SLR	SL (Km)	MSL (Km)	SLR	SL (Km)	MSL (Km)	SLR	SL (Km)	MSL (Km)	SLR
I	55.00	0.56	2.41	54.50	0.36	1.52	6.00	0.60	1.80	10.00	0.52	1.92	15.00	0.65	1.92	15.50	0.42	2.38
II	27.00	1.35	0.79	19.50	0.55	2.45	3.25	1.08	2.17	7.00	1.00	3.00	7.50	1.25	1.53	7.00	1.00	0.75
III	7.50	1.07	4.67	9.50	1.35	1.66	2.35	2.35		6.00	3.00		1.00	1.00		0.75	0.75	
IV	10.00	5.00		4.50	2.25													

ASTER

Stream Order	Rudarpur micro-watershed			Dobri micro-watershed			Chhorba micro-watershed			Chandpur micro-watershed			Jagatpur micro-watershed			Abdullahpur micro-watershed		
	SL (Km)	MSL (Km)	SLR	SL (Km)	MSL (Km)	SLR	SL (Km)	MSL (Km)	SLR	SL (Km)	MSL (Km)	SLR	SL (Km)	MSL (Km)	SLR	SL (Km)	MSL (Km)	SLR
I	57.00	0.28	2.89	49.50	0.25	1.80	15.00	0.31	1.71	13.00	0.30	2.23	12.00	0.17	5.59	17.00	0.28	3.18
II	29.25	0.81	2.09	14.00	0.45	5.06	4.75	0.53	6.60	6.00	0.67	2.23	11.50	0.95	5.26	10.75	0.89	0.28
III	15.25	1.70	1.32	16.00	2.28	1.28	7.00	3.50	0.10	3.00	1.50	1.13	5.00	5.00		0.25	0.25	
IV	9.00	2.25		11.75	2.93		0.75	0.37		2.00	2.00							

Table 4: Shape parameters of different drainage micro-watersheds

Toposheet and ASTER

Name of micro-watersheds	Basin Area (Km^2)	Maximum Basin Length (Km)	Basin Perimeter (Km)	Elongation Ratio (Re)	Circularity Ratio (Rc)	Form Factor (Rf)
Rudarpur	65.25	14.55	36.25	0.62	0.62	0.30
Dobri	58.00	20.10	46.05	0.42	0.34	0.14
Chhorba	17.00	7.20	17.60	0.64	0.68	0.32
Chandpur	15.00	8.95	19.25	0.48	0.50	0.18
Jagatpur	25.06	12.20	26.25	0.46	0.45	0.17
Abdullahpur	22.68	10.30	24.70	0.52	0.46	0.21

Table 5: Drainage Density, Stream Frequency, Drainage Texture, Infiltration Number and Length of Overland Flow

Name of the micro-watersheds	Drainage Density (Dd)		Stream Frequency (Fs)		Drainage Texture (Rt)		Infiltration Number (If)		Length of Overland Flow(Lg)	
	Topo sheet	ASTER	Topo sheet	ASTER	Topo sheet	ASTER	Topo sheet	ASTER	Topo sheet	ASTER
Rudarpur	1.52	1.69	1.96	3.77	3.53	6.78	2.98	6.37	0.33	0.30
Dobri	1.52	1.57	3.34	4.08	4.29	5.14	5.58	6.4	0.33	0.32
Chhorba	0.68	1.62	0.82	3.52	0.83	3.4	0.55	5.7	0.73	0.31
Chandpur	1.53	1.6	1.93	3.67	1.5	2.86	2.95	5.87	0.32	0.31
Jagatpur	0.93	1.13	1.19	3.31	1.14	3.16	1.1	3.74	0.53	0.44
Abdullahpur	1.02	1.23	1.98	3.22	1.82	3.16	1.98	3.96	0.48	0.40

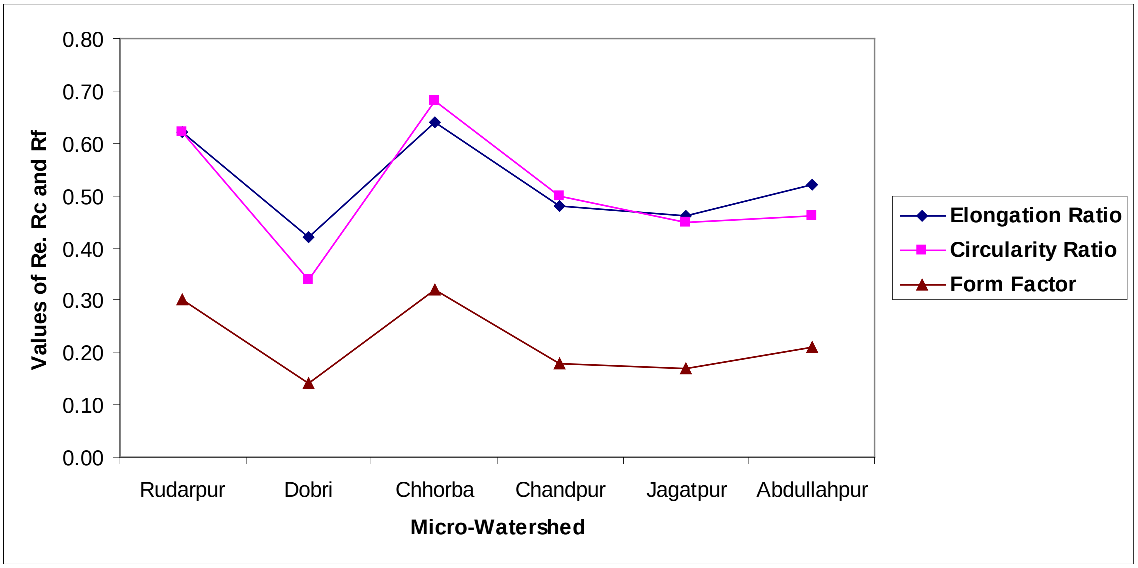
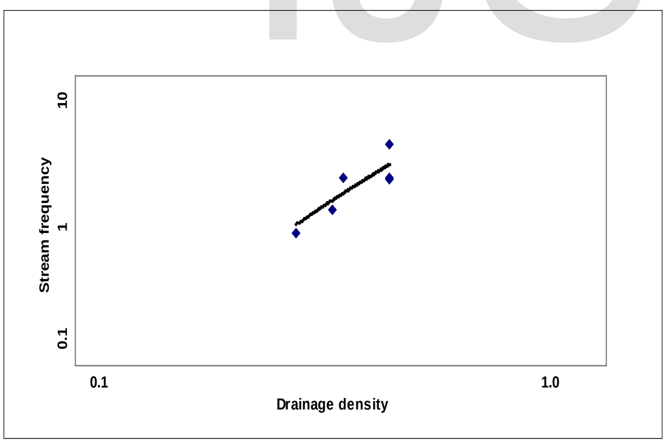


Figure 5: Plot showing shape parameters of different drainage micro-watersheds Toposheet and ASTER



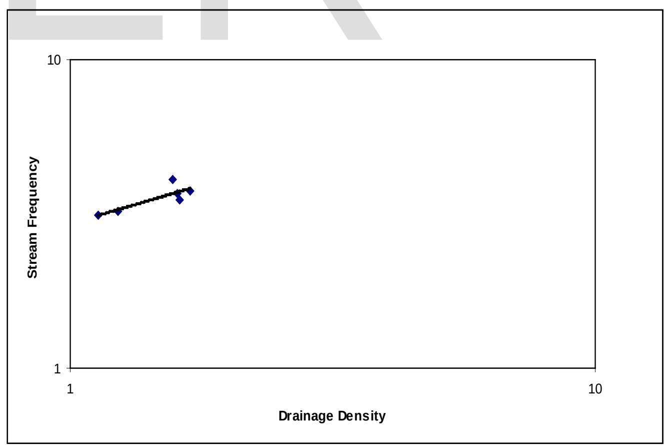


Figure 6.a: Log-log plot of Drainage Density Vs Stream Frequency (Toposheet)

Figure 6.b: Log-log plot of Drainage Density Vs Stream Frequency (ASTER)

Table 6: Parameters of Gradient Aspect of micro-watersheds

Toposheet

Name of micro-watersheds	Elevation		Max. Basin Relief (m)	Relief Ratio (m)	Relative Relief (Rhp)	Ruggedness Number (HD)
	Source point (m)	End Point (m)				
Rudarpur	907	471	0.44	0.029	0.08	0.66
Dobri	2229	509	1.72	0.085	0.18	2.61
Chhorba	509	452	0.057	0.0079	0.32	0.038
Chandpur	600	542	0.06	0.007	0.3	0.09
Jagatpur	933	563	0.37	0.03	1.4	0.34
Abdullahpur	1400	674	0.73	0.07	2.9	0.74

ASTER

Name of micro-watersheds	Elevation		Max. Basin Relief (m)	Relief Ratio (m)	Relative Relief (Rhp)	Ruggedness Number (HD)
	Source point (m)	End Point (m)				
Rudarpur	907	471	0.44	0.029	0.08	0.73
Dobri	2229	509	1.72	0.085	0.18	2.7
Chhorba	509	452	0.057	0.0079	0.32	0.09
Chandpur	600	542	0.06	0.007	0.3	0.09
Jagatpur	933	563	0.37	0.03	1.4	0.42
Abdullahpur	1400	674	0.73	0.07	3	0.89

References

Auden, J. B. (1934). The geology of the Krol belt. Rec. Geol Surv. Ind., 67,357-454.

Chow, V.T. (1964). Handbook of Applied Hydrology. Mc Graw Hill Co., New York, Ch (4):39-76.

Chopra, R., Dhiman, R., and Sharma, P.K. (2005). Morphometric analysis of sub-watersheds in Gurudaspur district, Punjab using Remote Sensing and GIS techniques. J. Indian Soc. Remote Sensing 33(4):531-539.

Gao, J. (1998). Impact of sampling intervals on the reliability of topographic variables mapped from grid DEMs at a micro-scale [J]. International Journal of Geographical Information Science 12: 875–890.

GSI, (1981). Geological and Mineralogical Map of Karnataka and Goa, Geological Survey of India.

Holmgren, P. (1994). Multiple flow direction algorithms for runoff modelling in grid based elevation models: an empirical evaluation [J]. Hydrological Processes 8:327-334.

Horton, R.E. (1932). Drainage basin characteristics. Trans. Am. Geophys. Union 13: 350-360.

Horton, R.E. (1945). Erosional development of stream and their drainage basin. Hydrogeological approach to quantitative morphology. Bull.Geol. Soc. Am., 56: 275-370.

Jha, V. K. (1995). Utility of satellite remote sensing in preliminary terrain evaluation for engineering geological projects (case example from Doon valley, U.P.). In: Sahai, B. (Ed), Proceedings of ISRS Silver Jubilee Symposium on Remote sensing for Environmental monitoring and Management with special emphasis on Hilly regions, NNRMS, Bangalore, 60-65.

Langbein, W.B. (1947). Topographic characteristic of Drainage Basin. U.S. Geol. Surv. Water-Supply Paper 986 (C) 157-159.

Li, Z.L.,and Zhu, Q. (eds) (2000). Digital elevation model [M]. Wuhan Technical University of Surveying and Mapping Press: Wuhan.

Martz, L.W., and Garbrecht, J. (1998). The treatment of flat areas and closed depressions in automated drainage analysis of raster digital elevation models. Hydrological Processes 12, 843-855.

Melton, M.A. (1957). An analysis of the relations among elements of climate, surface properties and geomorphology. Project NR 389-042, Tech. Rept. 11, Columbia University, Department of Geology, ONR, Geography Branch, New York.

Miller, V.C. (1953). A quantitative geomorphic study of drainage basin characteristic in the clinch, Mountain area, Verdinia and Tennesser, Project NR 389-042,Tech. Rept.3 Columbia University, Department of Geology, ONR, Geography Branch, New York.

Patton, P.C. (1988). Drainage basin morphometry and floods. In: Baker VR, Kochel RC, Patton PC (eds) Flood geomorphology. Wiley, USA, pp 51–65.

Richard, Kiss. (2004). Determination of drainage network in digital elevation models, utilities and limitations [J]. Journal of Hungarian Geomathematics 2:16-29.

Rupke, J. (1974). Stratigraphic and structural evolution of the Kumaun Lesser Himalaya Sed.Geol. 11, 2-4, 81-265.

Saran, S., Sterk, G., Peters, P., and Dadhwal, V. K. (2009). Evaluation of digital elevation models for delineation of hydrological response units in a Himalayan watershed. Geocarto International, 1–18, iFirst article.

Schumm, S.A. (1956). Evolution of drainage system and slope in badlands of Perth Amboy, New Jersey. Bull.Geol.Soc.Am. 67: 597-46.

Singh, S., and Singh, M.C. (1997). Morphomertric Analysis of Kanhar River Basin. National Geographical Jour. of India 43 (1):31-43.

Smith, (1950). Standards for Grading Textures of Erosional Topography. Am. Jour. Sc. 248: 655-668.

Strahler, A.N. (1952). Hypsometric (area-altitude) analysis of erosional topography. Bull. Geol. Am. 63: 1117- 1142.

Strahler, A.N. (1958). Dimensional analysis of watershed geomorphology. Bull. Geol. Am. 69: 279-300.

Strahler, A.N. (1964). Quantitative geomorphology of drainage basins and channel networks. In: Chow, V. (ed.) Handbook of applied hydrology. Section 4-II, p 39-76, McGraw-Hill Book Co., New York, 1964.

Tarboton, D.J. (1997). A new method for the determination of flow directions and upslope areas in grid digital elevation models [J]. Water Resources Research 33(2):309-319.

Tribe, A. (1992). Automated recognition of valley heads from digital elevation Models. Earth Surface Processes & Landforms, 16, 33–49.

Vittala, S. S., Govindaiah, S., and Honne Gowda, H. (2004). Morphometric analysis of sub watershed in the Pavagada area of Tumkur district, South India using remote sensing and GIS techniques.Jour.Indian Soc.Remote Sens.,v.32,pp.351-362.

Weibel, R., and Heller, M. (1991). Digital terrain modelling [J]. Geographical Information System 1:269-297.

Wise, S. (2000). Assessing the quality for hydrological applications of digital elevation models derived from contours [J]. Hydrological Processes 14: 1909–1929.