RESEARCH ARTICLE

GIS- based morphometric analysis of major watersheds of Tehran- Karaj, Central of Iran

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ABSTRACT

The study area, Tehran-Karaj plain is situated in central part of Iran, lies between latitudes 36°10′ to 35°04′ N and longitudes 50°38′, to 51°45′ E covering an area of 4762sq km comprising of 4 sub-watersheds (A,B,C and D). Morphometric analysis is important in any hydrological investigation and it is inevitable in development and management of drainage basin. The present study involves the Geographic Information System (GIS) analysis techniques to evaluate and compare linear relief and aerial morphometric of the 4 subwater sheds. The drainage network shows that the terrain exhibits dendritic to sub-dendritic drainage pattern. Stream orders ranges from fourth to fifth order. Drainage density varies between 0.21 and 0.4 km/km^2 and has very coarse to coarse drainage texture. The relief ratio is ranging from 0.004 to0.017. The mean bifurcation ratio varies from 2.37 to 3.77 and falls under normal basin category. The elongation ratio shows that 'C' watershed possesses circular shape while remaining sub-watersheds mark elongated pattern.

Keywords: Morphometric analysis, GIS and Remote sensing , Tehran – karaj water shed, sub water shed

INTRODUCTION

The assessment of hydrological characteristics of a drainage basin is a mandate for any basin management scheme. It involves a detailed morphometric analysis, which includes basin size, shape, slope of drainage area, drainage density, size and length of the tributaries, etc. Drainage basins are the fundamental units of the fluvial landscape and a great amount of research has focused on their geometric characteristics, which include the topology of the stream networks and quantitative description of drainage texture, pattern, shape, and relief characteristics (Abrahams 1984; Huggett and Cheesman 2002).

The correlation between physiographic characteristics of drainage basin to various hydrologic phenomena has been reported by Rastogi and Sharma (1976). In various articles, morphometric analyses were used for basin characterization (Miller 1953; Boulton 1968; Gregory and Walling

1973; Gardiner 1975; Costa 1987; Topaloglu 2002; Moussa 2003; Mesa 2006; Angillieri 2008; Magesh et al. 2011; Magesh et al. 2012, John Wilson et al. 2012). Delineation of drainage networks within a basin orsub-basinor watershed can be achieved using traditional methods such as field observations and topographic maps or alternatively with advanced methods using remote sensing and GIS-(Verstappen 1983; Rinaldo et al. 1998; Macka 2001; Maidment 2002; Ozdemir and Bird 2009). The major drawback in traditional approach is its tedious effort to examine all stream networks from field observations due to their extent over a vast area. On the other hand, extraction of drainage networks from digital elevation models (DEMs) is quite handy as it assumes that water will flow from higher to lower elevation using the steepest descent. But it requires systematic method to get the results. Unifying these steps in GIS model builder using appropriate geo-processing tools will produce an automated stream extraction model with supporting thematic layers such as aspect, slope, relief, and drainage density. The output of this model can be used for further morphometric analysis.

Study Area

The study area, Tehran-Karaj plain is situated in central part of Iran, lies between latitudes 36°10′ to 35°04′ N and longitudes 50°38′, to 51°45′ E covering an area of 4762sq km. The average height of the region is 4326 m above MSL (Fig.1).

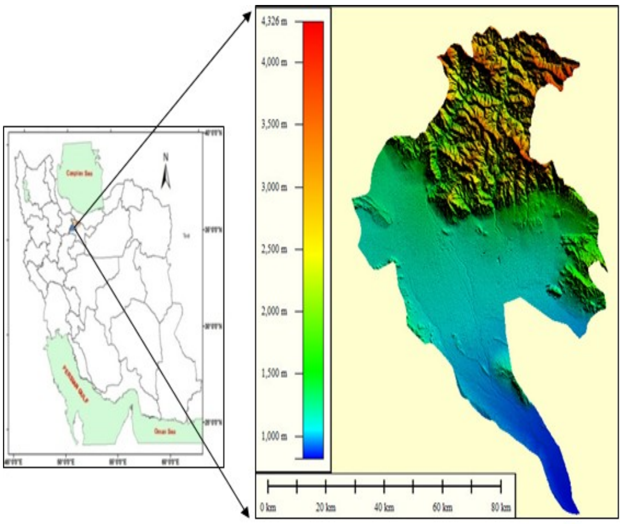

Fig. 1: Location map of the study area.

MATERIALS AND METHODS

In the present study, the map showing drainage details have been prepared from digital data of MR SIDE photo. These satellite images have been geo-referenced and merged using Image Processing software ERDAS IMAGINE9.1 and Global Mapper 15. Thus the merged data (Fig. 2) were used in the study area.

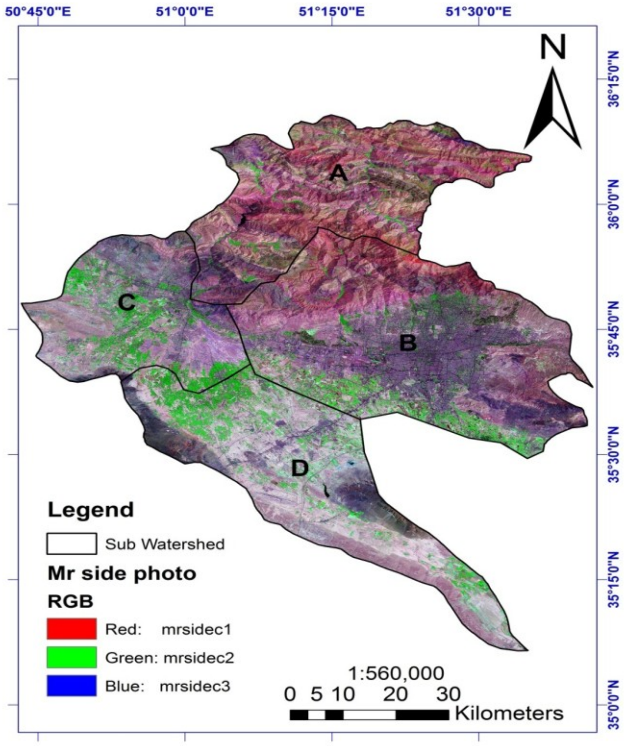

Fig. 2. Sub-watersheds on satellite image of the study area use Mrside photo

The drainages have been delineated using merged satellite data of on 1:50,000 scale and SOl toposheets have been used as a reference. The morphometric parameters considered for the analysis are summarized in detail in Table 1. GIS software like ArcInfo (V 10.2.2) have been used for digitization and computational purpose and also for output generation.

RESULTS AND DISCUSSION

The present study emphasizes the use of satellite remote sensing and Arc GIS for morphometric analysis and the results are discussed below.

Watershed Delineation

Watershed is a natural hydrological entity from which surface runoff flows to a defined drain, channel, stream or river at particular point. The entire area has been divided into 4 watersheds (Table 2). The watersheds have been named as based on the Alphabetical listing at the outlet. (Fig. 3).

Delineation of Drainage Network

The present drainage network in the 4 watersheds delineated using merged satellite data (Fig. 2)

Morphometric Analysis

Morphometric is the measurement and mathematical analysis of the configuration of the Earth's surface, shape and dimensions of its landforms (Clarke, 1966). This analysis can be achieved through measurement of linear, aerial and relief aspects of the basin and slope contributions (Nag and Chakraborty, 2003). In the present study, the morphometric analysis for the parameters namely stream order, stream length, bifurcation ratio, stream length ratio, basin length, drainage density, stream frequency, elongation ratio, circularity ratio, form factor, relief ratio, etc., has been carried out using the mathematical formulae given in Table 1 and the results are summarized in Table2.

Table 1: Methodology adopted for computations of morphometric parameters.

S.N.	Mophometric Parameters	Formula	Reference
1	Stream Order	Hierarchial rank	Strahler (1964)
2	Stream Length (Lu)	Length of the Stream	Horton (1945)
3	Mean Stream Length (Lsm)	Lsm = Lu t Nu Where, Lsm = Mean Stream Length Lu = Total stream length of order 'u' Nu = Total no. of stream segments of order 'u'	Strahler (1964)
4	Stream Length Ratio (RL)	RL=Lu/Lu-I Where, RL = Stream Length Ratio Lu = The total stream length of the order 'u' Lu - I = The total stream length of its next lower order	Horton (1945)
5	Bifurcation Ratio (Rb)	Rb= Nu/Nu+ 1 Where, Rb - Bifurcation Ratio Nu = Total no. of stream segments of order 'u' Nu + 1 = Number of segments of the next higher order	Schumn (1956)
6	Mean bifurcation ratio (Rbm)	Rbm = Average of bifurcation ratios of all orders	Strahler (1957)
7	Relief Ratio (Rh)	Rh = H / Lb Where, Rh = Relief Ratio H =Total relief (Relative relief)of the basin in Kilometers Lb = Basin length	Schumm(1956)
8	Drainage density (Dd)	D=Lu/A Where, D = Drainage Density Lu = Total stream length of all orders A = Area of the Basin (km'-)	Horton (1932)
9	Stream Frequency (Fs)	Fs=Nu/A Where, Fs = Stream Frequency Nu = Total no. of streams of all orders A = Area of the Basin (km-')	Horton (1932)
10	Drainage Texture (Rt)	Rt=Nu/P Where, Rt = Drainage Texture Nu = Total no. of streams of all orders P = Perimeter (km)	Horton (1945)
11	Form Factor (Rf)	Rf = A / Lb 2 Where, Rf = Form Factor A = Area of the Basin (km-') Lb 2 = Square of Basin length	Horton (1932)
12	Circularity Ratio (Rc)	Re=4* Pi*A/P 2 Where, Rc = Circularity Ratio Pi = 'Pi' value i.e., 3.14 A = Area of the Basin (kin 2) p2 = Square of the Perimeter (Km)	Miller (1953)
13	Elongation Ratio (Re)	Re **= 2 v (A / Pi) /** Lb Where, Re = Elongation Ratio A = Area of the Basin (km'-) Pi = 'Pi' value i.e., 3.14 Lb = Basin length	Schumn (1956)
14	Length of Overland flow (Lg)	Lg=l/D*2 Where, Lg = Length of Overland flow D = Drainage Density	Horton (1945)

Table 2: Results of morphometric analysis of 4 watersheds

SWSD No.	Stream Order	Basin Area (km2)	Stream order (Sμ)					Stream length (Lμ) (kms)					Perimeter (P) (km)	Basin length (km)
			I	II	III	IV	V	I	II	III	IV	V		
A	IV	1096.8	43	10	2	1	-	275	59.9	15.2	49.97	-	186.61	57.2
B	IV	1687.8	35	10	2	1	-	190	97.9	65.15	1.17	-	185.29	45.8
C	V	788.37	38	10	3	2	1	170.4	83.92	25.93	17.8	18.35	126.11	25.3
D	V	1189.2	11	2	1	1	1	81.51	8.4	55.55	2.1	81.96	201.45	76.1

SWSD No	Mean Stream Length in Km (Lsm)					Stream Length Ratio (RL)				Total Relief (M)	Relief Ratio (Rh)	Elongation Ratio (Re)	Texture Ratio (Rt)
	I	II	III	IV	V	II /I	III /II	IV /III	V /IV				
A	6.4	5.99	7.6	49.97	-	0.22	0.25	3.29	-	1000	0.017	0.65	0.98
B	5.43	9.79	32.57	1.17	-	0.52	0.67	0.018	-	350	0.008	1.01	1.05
C	4.48	8.39	8.64	8.9	18.35	0.49	0.31	0.69	1.04	154	0.006	1.25	2.13
D	7.41	4.2	27.7	2.1	81.96	0.1	6.61	0.038	39.02	299	0.004	0.51	0.21

SWSD No	**Bifurcation Ratio (Rb)**				Mean Bifurcation Ratio (Rbm)	Drainage Density (D) (km/km 2)	Stream Frequency (Fs)	Form Factor (Rf)	Circularity Ratio (Rc)	Length of Overland Flow (Lg)
	I /II	**II/ III**	**III /IV**	**IV /V**						
A	**4.3**	**5**	**2**	**-**	**3.77**	**0.36**	**0.051**	**0.34**	**0.4**	**1.39**
B	**3.5**	**5**	**2**	**-**	**3.5**	**0.21**	**0.028**	**0.8**	**0.62**	**2.38**
C	**3.8**	**3.33**	**1.5**	**2**	**2.66**	**0.4**	**0.068**	**1.24**	**0.62**	**1.25**
D	**5.5**	**2**	**1**	**1**	**2.37**	**0.19**	**0.014**	**0.2**	**0.37**	**1.35**

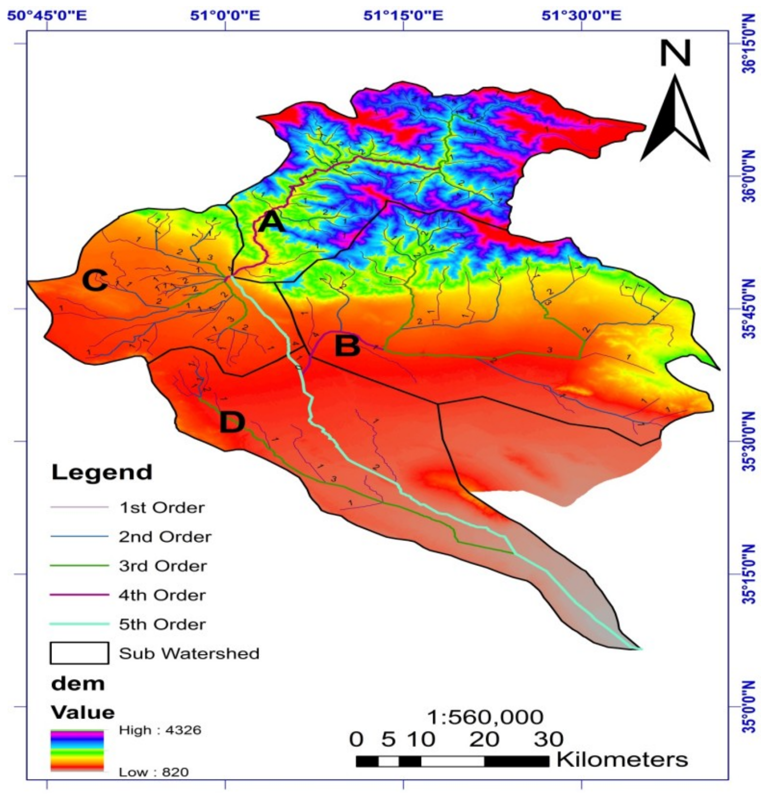

Fig. 3. Sub-watersheds showing stream orders.

Linear Aspect

Stream order, stream length, mean stream length, stream length ratio and bifurcation ratio are linear aspects, that were determined and results have beengiven in Table 2.

Stream Order:

The designation of stream orders is the first step in drainage basin analysis and is based on a hierarchic ranking of streams. In the present study, ranking of streams has been carried out based on the method proposed by Strahler (1964) (Table 1). The order wise stream numbers, area and stream lengths of the 4 watersheds are given in Table2. Out of these watersheds, 'A' and 'B' are of fourth order, while remaining sub watersheds namely 'C' and 'D' are of fifth order. It is observed from the Table 2 that the maximum frequency is in case of first order streams. It is also noticed that there is a decrease in stream frequency as the stream order increases.

Stream length:

The number of streams of various orders in a watershed are counted and their lengths from mouth to drainage divide are measured (Table 2) with the help of GIS software. The stream length (Lu) has been computed based on the law proposed by Horton (1945) for all the 4 watersheds (Table 1). Generally, the total length of stream segments is maximum in first order streams and decreases as the stream order increases. (Table 2). This change may indicate that the flowing of streams from high altitude, with lithological variation and moderately steep slopes (Singh and Singh, 1997).

Mean stream length

According to Strahler (1964), the mean stream length is a characteristic property related to the drainage network and its associated surfaces. The mean stream length (Lsm) has been calculated by dividing the total stream length of order 'u' and number of streams of segment of order 'u' (Table1). It is noted from the results (Table 2) that Lsm varies from 1.17 to 81.96 and Lsm of any given order is greater than that of the lower order and less than that of its next higher order in 'C' and 'D'-watersheds..

Stream Length Ratio

Stream length ratio (RL) may be defined as the ratio of the mean length of the one order to the next lower order of stream segment (Table 1). Horton's law (1945) of stream length states that mean stream length segments of each of the successive orders of a basin tends to approximate a direct geometric series with streams length increasing towards higher order of streams. The RL between streams of different order in the study area reveals that there is a variation in RL in each sub-watershed (Table2). This variation might be due to changes in slope-and topography. A and B sub-watersheds show an increasing trend in the length ratio from lower order to higher order indicating their mature geomorphic stage. Whereas in remaining sub-watersheds, there is a change from one order to another order indicating their late youth stage of geomorphic development (Singh and Singh, 1997).

Bifurcation Ratio

The term bifurcation ratio (Rb) may be defined as the ratio of the number of the stream segments of given order to the number of segments of the next higher order (Schumn, 1956) (Table 1). Horton (1945) considered the bifurcation ratio as an index of relief and dissections. Strahler (1957) demonstrated that bifurcation ratio shows a small range of variation for different regions or for different environment except where the powerful geological control dominates. It is observed from the Table 2, the Rb is not same from one order to its next order. These irregularities are dependent upon the geological and lithological development of the drainage basin (Strahler, 1964). The lower values of Rb are characteristics of the sub-watersheds which have suffered less structural disturbances (Strahler, 1964) and the drainage patterns has not been distorted because of the structural disturbances (Nag, 1998). In the present study, the higher values of Rb indicates strong structural control on the drainage pattern while the lower values indicative of subwater sheds that are not affected by structural disturbances. The mean bifurcation ratio (Rbm) may be defined as the average of bifurcation ratios of all orders (Table 1). In the present case, Rbm varies from2.37 to 3.77 (Table 2) and all sub-watersheds fall under normal basin category (Strahler, 1957).

Relief Aspect

The relief measurements like relief ratio, basin length and total relief are tabulated in Table 2.

Relief Ratio

The elevation difference between the highest and lowest points on the valley floor of a sub watershed is known as the total relief of that sub watershed. The relief ratio (Rh) of maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line is termed as relief ratio (Schumm, 1956) (Table 1). According to him, there is direct relationship between the relief and channel gradient. There is also a correlation between hydrological characteristics and the relief ratio of a drainage basin. The Rh normally increases with decreasing drainage area and size of sub-watersheds of a given drainage basin (Gottschalk, 1964). The values of Rh are given in Table 2 and ranges from 0.004 to 0.017. It is noticed that the high values of Rh indicate steep slope and high relief (1000 m), while the lower values indicate the presence of basement rocks that are exposed in the form of small ridges and mounds with lower degree of slope (Table 2).

Aerial Aspect

Different morphometric parameters like drainage density, texture ratio, stream frequency, form factor, circularity ratio, elongation ratio and length of overland flow have been discussed in detail and are presented in Table 2.

Drainage density (Dd)

The drainage density is an expression of the closeness or spacing of channels (Horton, 1932). The significance of drainage density is recognized as a factor determining the time travel by water (Schumm, 1956). The measurement of Dd is a useful numerical measure of landscape dissection and runoff potential (Chorley, 1969). On the one hand, the Dd is a result of interacting factors controlling the surface runoff on the other hand, it is itself influencing the output of water and sediment from the drainage basin (Ozdemir and Bird, 2009). Dd is known to vary with climate and vegetation, soil, rock properties, relief and landscape evolution processes (Kelson and Wells, 1989; Oguchi, 1997; Moglen et al., 1998; Srinivasa et al., 2004). The amount and type of precipitation influences directly the quantity and character of surface run-off. An area with high precipitation such as thundershowers loses greater percentage of rainfall as run-off resulting in more surface drainage lines. Amount of vegetation and rainfall absorption and infiltration capacity of soils, which influences the rate of surface run-off, affects the drainage texture of an area. The similar condition of lithology and geologic structures; semi-arid regions have finer drainage density texture than humid regions. According to Nag (1998), low drainage density generally results in the areas of highly resistant or permeable subsoil material, dense vegetation and low relief. High drainage density is the resultant of weak or impermeable subsurface material, sparse vegetation and mountainous relief. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture.

In the present area, the drainage density varies between 0.21 and 0.4 km/km^2 indicating low drainage density (Table2). It is suggested that this low drainage density indicates the region has highly permeable subsoil. Moreover the study area has low rainfall due to semiarid conditions.

Stream Frequency

The stream frequency (Fs) or channel frequency or drainage frequency of a basin may be defined as the total number of stream segments within the basin per unit area_(Horton, 1945). Hypothetically, it is possible to have the basin of same drainage density differing in stream frequency and basins of same stream frequency differing in drainage density. Table 2 shows Fs for all sub-watersheds of the study area. In the area it is noted that the Fs exhibits positive correlation with the drainage density values of the sub-watersheds indicating the increase in stream population with respect to increase in drainage density.

Drainage Texture

The drainage texture ratio is considered as one of the important concept of geomorphology which shows the relative spacing of the drainage lines (Chorley et al., 1957). According to Horton (1945), Rt is the total number of stream segments of all orders per perimeter of that area (Table 1). He recognized infiltration capacity is the single important factor which influences Rt and considered drainage texture which includes drainage density and stream frequency. Smith (1950) has classified drainage density into five different textures. The drainage density less than 2 indicates very coarse, between 2 and 4 is related to coarse, between 4 and 6 is moderate, between 6 and 8 is fine and greater than8 is very fine drainage texture. In the present area, the drainage density (Table 2) is of very coarse to coarse drainage texture.

Form Factor

Quantitative expression of drainage basin outline form through a form factor ratio (Rf), which is the dimensionless ratio of basin area to the square of basin length (Horton, 1932). (Table 1). From Table 2 it is observed that the Rf varies between 0.2 'D' and 1.24 'C' and thus indicates that the 'C' sub-watershed is circular in shape with higher value(1.24) whereas the remaining sub-watersheds are elongated with lower values of form factor.

Circularity Ratio

The circularity ratio (Rc) has been used as a quantitative measure for visualizing the shape of the basin and is expressed as the ratio of basin area 'A' to the area of a circle (Ac) having the same perimeter as the basin (Miller1953; Strahler 1964). It is affected by the lithological character of the basin. The ratio is more influenced by length, frequency (Fs), and gradient of streams of various orders rather than slope conditions and drainage pattern of the basin. It is a significant ratio, which indicates the dendritic stage of a basin. Its low, medium and high values are indicative of the youth, mature and old stages of the life cycle of the tributary basins. In the present study, the Rc (Table 2) ranges from0.37 to 0.62. High Rc 0.53 in 'B' and 'C'subwater sheds and 0.40 in 'A' sub-watershed indicates that they are more or less circular and are characterized by high to moderate relief and drainage system is structurally controlled. The remaining 'D' sub watershed has less than 0.40 indicating that they are elongated.

Elongation Ratio

Elongation ratio (Re) is defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length (Schumm, 1956). It is a very significant index in the analysis of basin shape which helps to give an idea about the hydrological character of a drainage basin. A circular basin is more efficient in the discharge of run-off than an elongated basin (Singh and Singh, 1997). The values of Re generally vary from 0.6 to 1.0 over a wide variety of climatic and geologic types. Values close to 1.0 are typical of regions of very low relief, whereas values in the range 0.6 - 0.8 are usually associated with high relief and steep ground slope (Strahler, 1964).

The lowest Re (0.51) in case of 'D'sub-watershed indicates, high relief and steep slope, while very high values in 'C' sub-watershed (1.25) indicates that plain land with low relief and low slope. Further, it reveals that the 'C' sub-watershed is circular whereas the remaining sub-watersheds are elongated.

Length of Overland flow

It is the length of water over the ground before it gets concentrated into definite stream channels (Horton, 1945) (Table 1). This factor basically relates inversely to the average slope of the channel and is quite synonymous with the length of sheet flow to a large degree. The length of overland flow (Lg) approximately equals to half of the reciprocal of drainage density (Horton, 1945). Table 2 reveals that the Lg is less in 'C'sub-watershed as drainage density is high in this sub-watershed when compared to remaining sub-watersheds. The computed value of Lg for all sub-watersheds varies from 1.25to 2.38.

CONCLUSION

The drainage basin is being frequently selected as a unit of morphometric analysis because of its topographic and hydrological unity. GIS software have resulted to be of immense utility in the analysis of the Linear and Areal morphometric aspects of the drainage basins. The study reveals that GIS based approach in evaluation of drainage morphometric parameters at river basin level is more appropriate than the conventional methods. GIS based approach facilitates analysis of different morphometric parameters and to explore the relationship between the drainage morphometric and properties of landforms, soils and eroded lands.

The morphometric analysis of the drainage networks of all 4 sub-watersheds exhibits the dendritic to sub dendritic drainage pattern and the variation in stream length ratio might be due to changes in slope and topography.

The study area exhibited the mature stage of streams in 'A' and 'B' sub-watersheds and late youth stage of geomorphic development in remaining sub-watersheds. The variation in values of bifurcation ratio among the sub-watersheds is ascribed to the difference in topography and geometric development. The stream frequencies for all sub-watersheds of the study area exhibit positive correlation with the drainage density indicating the increase in stream population with respect to increase in drainage density. Drainage density is very coarse to coarse texture. Elongation ratio shows that 'C' sub-watershed possesses circular shape, while the remaining marks elongated pattern.

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