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Morphometric Analysis Using Arc GIS Techniques A Case Study of Chamarajanagara District, Karanataka, India

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Abstract-Morphometric Anaysis is the measurement and mathematical analysis of the configuration of Earth surface, shape and dimensions of its landforms. Morphometric analysis gives overall view of the terrain information like hydrological, lithological, slope, relief, variations in the watershed, ground water recharge, porosity, soil characteristics, flood peak, rock resistant, permeability and runoff intensity and is useful for geological, hydrological, ground water prospects, civil engineering and environmental studies. The main objective of this study is to find the watershed characteristics and stream properties from the measurement of various stream attributes. The watershed analysis is done aspect wise such as linear aspects and aerial aspects. The linear aspects include stream order, stream number, stream length, and bifurcation ratio, mean length of stream orders, stream length ratio and mean stream length ratio. Areal aspects comprise drainage density, form factor, drainage texture and elongation ratio. Morphometric analysis of Chamarajanagara district is carried out using Arc GIS (10.2) software. The analysis reveals that in entire Chamarajanagara district has been divided into 17 subwatersheds with stream order varying from 1 to 7. The study area is having uniform lithology and structurally permeable. The low drainage density of all subwatersheds indicates that the study area indicates less surface runoff. An immense control of structure on the drainage in found in some subwatersheds is indicated by their high bifurcation ratios. The analysis also indicates that the subwatersheds are having drainage texture varying from course to fine texture. Elongation ratio and form factor shows that the subwatersheds have elongated to circular shapes. From the integrated morphometric analysis, important hydrologic characteristics of 17 subwatersheds could be inferred.

Keyword: - Chamarajanagara District, Subwatersheds, Digital Elevation Model (DEM), Watershed delineation, Stream order, Stream number, Stream length, Bifurcation ratio, Length of stream orders, Stream length ratio, Mean stream length ratio, Drainage density, Form factor, Drainage texture and Elongation ratio.

I. INTRODUCTION

Morphometric Anaysis is the measurement and mathematical analysis of the configuration of Earth surface, shape and dimensions of its landforms. In order to understand the drainage behavior, quantitative methods have been developed. In hydrological study, drainage behavior are very important in understand hydrological processes [1]. As watershed is the basic unit in hydrology, hence, morphometric analysis at watershed scale is advantageous and preferable rather than to carry it out on individual channel or segmental areas. Watershed is an area whose runoff is conveyed to a single outlet and is an appropriate unit to study processes of the land surface. This study describes the drainage characteristics of Chamarajanagara district which is located in the southern tip of Karnataka. The district has a territory of 5,648 square kilometers and undulating and mountainous with north south trending hill ranges of both Eastern and Western Ghats. The district is located 185 kms away from Bangalore state capital and lies between the North latitude 11° 40` 58`` and 12º 06` 32`` and East longitude 76º 24` 14`` and 77º 46` 55`` with an altitude of 1816m above mean sea level. The location map of the study area is as shown in Figure 1. The district has been segregated into 4 Taluks namely Chamarajanagara Taluk, Gundlupet Taluk, Kollegal and Yalandur Taluks. The district falls under semi-Arid Monsoon climatic zone. The district records as whole 764 mm of annual average precipitation with 47 rainy days. During summer seasons the temperature may range from 32.6ºc to 34ºc and during winter season 16.4ºc to 25ºc. Relative humidity ranges from 69 to 85% during morning hours and during evening it ranges from 21 to 70%. The wind speed will range from 8.4 to 14.1 kmph.

Chamarajanagara district soils are derived from Granitic gneisses and Charnockite rocks. Large area of the district is covered by Medium deep, red gravelly clay soils, mostly seen in the upland areas. Chamarajanagara district falls in Cauvery river basin. There are no major rivers flowing in the district, however Cauvery the perennial river flows along the border of Kollegal taluk of Chamarajanagara district with its tributaries like Suvarnavathy and Chikkahole. The major crops grown in Chamarajanagara district are Paddy, Ragi, Jowar, Bajra and Maize. Major pulses are Gram and Tur and oil seeds grown in Chamarajanagara district are Groundnut and Sun Flower. In order to better understanding of the basin development and management, various morphometric parameters such as linear and aerial aspects studies are very important. Thus, morphometric techniques is important in the quantitative and qualitative description of geometry and network of drainage basins. Morphometric analyses of any region provides preparation of the detailed drainage map such as stream order, catchment area and its perimeter, stream length and mean stream length etc.

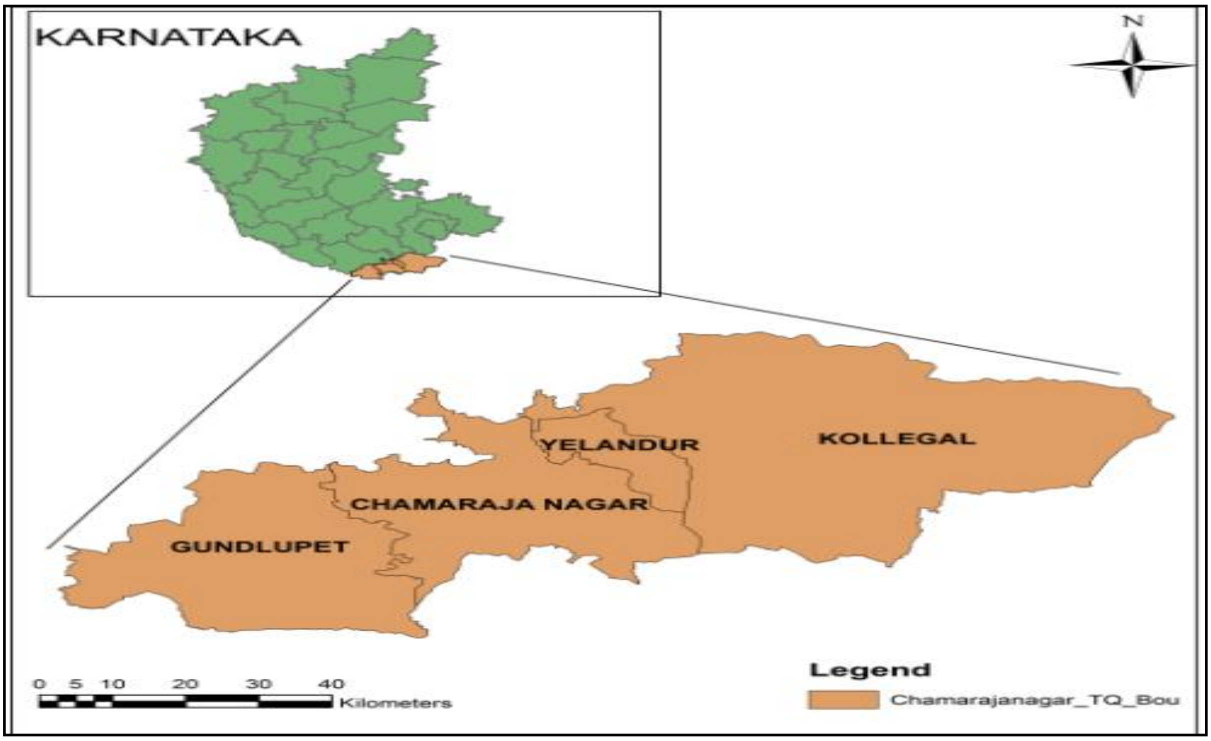

Fig-1: Location map of Chamarajanagara District

II. MATERIALS AND METHOD

A. Data Used

The data used in this study is Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) 30m DEM.

B. Watershed Delineation

Watersheds, are known as basins, are physically delineated by the area upstream from a specified outlet point. Watersheds can be delineated manually using paper maps, or digitally in Arc GIS. Watershed delineation creates a boundary that represents the contributing area for a particular control point or outlet and is also used to define boundaries of the study area, and/ or to divide the study area to sub-areas. Delineation is a process known as watershed segmentation, i.e., dividing the watershed into discrete land and channel segments to analyze watershed behavior. It is required to know the basin watershed characteristics. Watershed can be delineated using DEM (Digital Elevation Model) data which is having grid size resolution of 30m. Often errors may occur due to resolution of the data or rounding of elevation to the nearest integer value, sinks will be formed. Sinks should be filled to ensure proper delineation of basins and streams. If the sinks are not filled, a derived drainage network may be discontinuous. Hence the “Fill” tool in the Hydrology toolbox is used to remove sinks in the DEM. Next is creating a raster of “Flow direction” from each cell to its steepest down slope neighbor. Now create a “Flow Accumulation” raster which gives the accumulated flow into each cell. A suitable weight factor can be applied [3].

Weight factor of 150 is applied for the given study area. After getting the flow accumulation raster, pour points are required to determine watershed pertaining to the flow path. We create a point shape file for determining the pour points. These pour points are determined in the path using flow accumulation raster. Using the watershed tool in hydrology tool box, the watersheds are delineated. The inputs required are the flow direction raster and the pour point shape file. Boundaries of the 17 subwatersheds were derived by defining pour point for each subwatershed as shown in Figure 2.

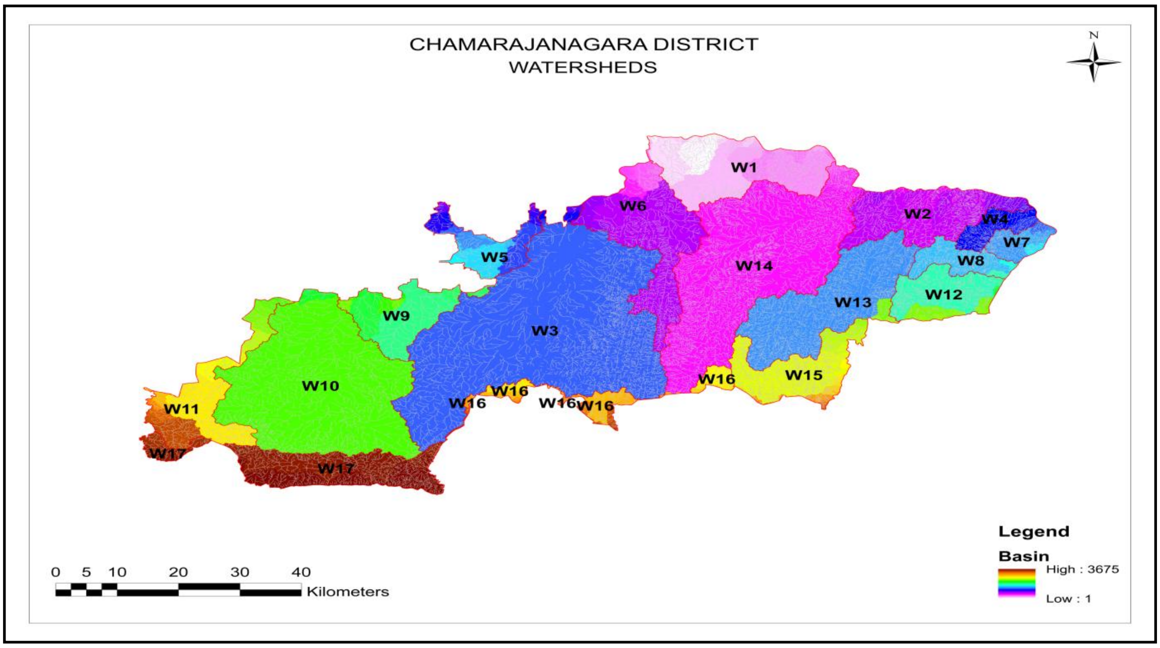

Fig-2: Subwatersheds along with stream lines in Chamarajanagara district

C. Quantitative Morphometry

In the present study, morphometric analysis of the parameters, such as, stream order, stream length, bifurcation ratio, drainage density, drainage texture, stream frequency, drainage texture, form factor, elongation ratio, area, perimeter, and length of all the 17 subwatersheds have been carried out using the standard mathematical formulae given in the Table 1 [2]. The values of various basin characteristics required for calculating morphometric parameters are shown in Table 2.

Table-1: Methodology adopted for computation of morphometric parameters.

Morphometric Parameters	**Methods**	**References**
Stream Order (U)	Hierarchical order	Strahler, 1964
Stream Length (Ln)	Length of the stream	Horton, 1945
Mean Stream Length (Lu)	Lu=Ln/Nu, where Ln=Stream length of order 'U', Nu=Total number of stream segments of order 'U'	Horton, 1945
Stream Length Ratio (Rl)	Rl=Lu/Lu-1, Lu=Mean stream length of order 'U',Lu-1=Mean stream length of next lower order	Horton, 1945
Bifurcation ratio (Rb)	Rb = Nu/ Nu+1; where, Nu=Total number of stream segment of order 'U', Nu+1=Number of segment of next higher order	Schumn,1956
Drainage density (Dd)	Dd = ∑Ln/Au where, L=Total length of streams, A=Basin area	Horton, 1945
Stream Frequency (Fs)	Fs=∑Nu/A where, Nu=Total number of streams in the basin, Au=Basin area	Horton, 1945
Drainage Texture	Drainage Texture=Dd*Fu, where, Dd=Stream density, Fu= Stream frequency	Horton, 1945
Form factor (Rf)	Rf=Au/(Lb)^2 ,where, A=Basin area, Lb=Basin length	Horton, 1932
Elongation ratio (Re)	Re=2√(A/π)/Lb , where, A=Area of watershed, π=3.14, Lb=Basin length	Schumn,1956

Table-2: Some important basin characteristics

Subwatershed	Basin Area (km^2)	Perimeter (km)	Basin Length (km)
W1	326	106	19
W2	253	136	19.45
W3	1220	277	76.36
W4	65	46	17.6
W5	134	106	12.9
W6	340	156	11.81
W7	60	39	10.09
W8	87	117	22.9
W9	186	89	21.66
W10	806	175	51.23
W11	229	157	19.12
W12	163	98	15.15
W13	401	302	32.5
W14	796	242	62.54
W15	207	195	28.86
W16	100	151	8.28
W17	275	153	17.94

III. RESULT AND DISCUSSION

1) Stream Order (U)

The first step in the drainage basin analysis is designation of stream orders which is the measure of the degree of stream branching within a watershed. Each length of stream is indicated by its order [1]. The highest stream order among 17 subwatersheds is seven and is shown in two subwatersheds and they are W3 and W10. The lowest stream order is four and is shown in four subwatersheds and they are W5, W7, W16 and W17. Higher stream order has greater discharge and higher velocity. There are only four subwatershed which are having higher stream order, they are W3 and W10 have U=7 and W13 and W14 have U=6. Hence these watersheds (W3, W10, W13 and W14) clearly contribute more to discharge and since higher velocity enhances the erosion rates, therefore, this side also contributes higher sediment loads. Also, the total number of stream segments decrease with stream order. This is known as Horton's law of stream numbers. Any deviation indicates that the terrain is having moderately steep slopes, underlain by varying lithology and probable uplift across the basin. In practice, when logarithms of the number of streams of a given order, are plotted against the order, the points lie on a straight line except few slight deviation. The Table 3 shows the stream order, stream number and stream length of the 17 subwatersheds and Figure 3 shows the relation between steam order and number of streams for 17 watersheds.

Table-3: Showing stream order, stream number and stream length of watersheds.

Subwatershed	Stream Order	Stream Number							Stream Length (km)						
		I	II	III	IV	V	VI	VII	I	II	III	IV	V	VI	VII
W1	5	786	143	49	7	1	-	-	277.4	148.5	101.7	36.2	10.1	-	-
W2	5	506	210	52	6	1	-	-	197.2	112.7	72.8	21.2	6.3	-	-
W3	7	2775	596	142	52	6	2	1	1092.3	578.3	325.6	146.9	109.5	33.0	18.0
W4	5	163	33	6	5	1	-	-	63.1	27.7	13.4	7.0	8.5	-	-
W5	4	319	65	19	5		-	-	130.3	66.2	36.1	21.8	-	-	-
W6	5	690	161	37	8	1	-	-	295.9	180.3	98.6	33.1	33.8	-	-
W7	4	164	19	4	1		-	-	53.1	26.5	18.5	2.7	-	-	-
W8	5	203	42	9	3	1	-	-	76.4	37.2	16.7	3.8	15.2	-	-
W9	5	477	96	45	4	1	-	-	180.3	88.9	50.2	29.3	2.1	-	-
W10	7	1756	437	95	49	5	4	1	760.8	381.9	240.1	117.9	34.2	44.9	6.8
W11	5	561	95	34	2	1	-	-	213.7	108.0	52.5	17.0	4.1	-	-
W12	5	349	80	12	2	1	-	-	125.4	72.7	32.7	19.8	4.8	-	-
W13	6	855	210	40	8	16	1	-	313.8	190.3	103.2	35.7	41.0	12.0	-
W14	6	1847	334	100	14	6	3	-	749.4	368.4	205.3	105.8	70.2	21.0	-
W15	5	469	138	29	4	3	-	-	168.4	87.3	60.2	8.9	17.4	-	-
W16	4	180	50	13	2	-	-	-	87.9	45.4	18.5	9.2	-	-	-
W17	4	655	126	38	3	-	-	-	226.7	139.9	65.1	20.7	-	-	-

2) Stream Length (Ln) / Mean Stream Length (Lu)

Stream length is the length of the stream of a particular order. It gives the surface runoff characteristics of relatively small areas with larger slopes and finer textures. It is the average stream length of the particular order. Analysis of the results as shown in Table 3 and 4 shows that the total length of stream segment is the maximum in case of first order stream. It decreases as the stream order increases in all the 17 watersheds. The result reaffirms the fact that the area is underlain with uniform lithology with no probable basin upliftment.

Table-4: Showing comparative mean stream length and stream length ratios

Subwatershed	Mean Stream Length							Stream Length Ratio					
	I	II	III	IV	V	VI	VII	II/I	III/II	IV/III	V/IV	VI/V	VII/VI
W1	0.4	1.0	2.1	5.2	10.1	-	-	2.9	2.0	2.5	2.0	-	-
W2	0.4	0.5	1.4	3.5	6.3	-	-	1.4	2.6	2.5	1.8	-	-
W3	0.4	1.0	2.3	2.8	18.2	25.0	33.0	2.5	2.4	1.2	6.5	1.8	0.5
W4	0.4	0.8	2.2	1.4	8.5	-	-	2.2	2.7	0.6	6.1	-	-
W5	0.4	1.0	1.9	4.4		-	-	2.5	1.9	2.3		-	-
W6	0.4	1.1	2.7	4.1	33.8	-	-	2.6	2.4	1.6	8.2	-	-
W7	0.3	1.4	4.6	2.7		-	-	4.3	3.3	0.6		-	-
W8	0.4	0.9	1.9	3.8	5.1	-	-	2.4	2.1	2.1	1.3	-	-
W9	0.4	0.9	1.1	7.3	2.1	-	-	2.4	1.2	6.6	0.3	-	-
W10	0.4	0.9	2.5	2.4	6.8	11.2	6.8	2.0	2.9	1.0	2.8	1.6	0.6
W11	0.4	1.1	1.5	8.5	4.1	-	-	3.0	1.4	5.5	0.5	-	-
W12	0.4	0.9	2.7	9.9	4.8	-	-	2.5	3.0	3.6	0.5	-	-
W13	0.4	0.9	2.6	4.5	2.6	12.0	-	2.5	2.8	1.7	0.6	4.7	-
W14	0.4	1.1	2.1	7.6	11.7	7.0	-	2.7	1.9	3.7	1.5	0.6	-
W15	0.4	0.6	2.1	2.5	5.8	-	-	1.8	3.3	1.1	2.6	-	-
W16	0.5	0.9	1.4	4.6	-	-	-	1.9	1.6	3.2	-	-	-
W17	0.3	1.1	1.7	6.9	-	-	-	3.2	1.5	4.0	-	-	-

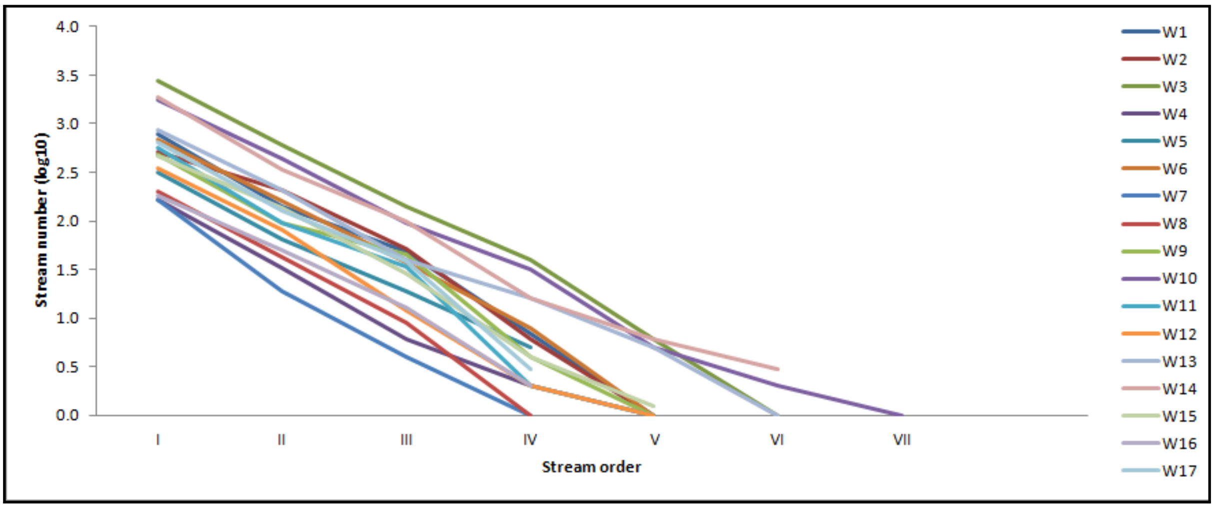

Fig-3: Showing the relation between steam order and number of streams for 17 subwatersheds

3) Bifurcation Ratio (Rb)

It is the ratio between the number of streams of any given order and the number of streams in the next higher order. If the value of Rb varies between 3 and 5, the rock type is homogenous. When it is more than 5, the basin is elongated and geological structure controls the basin. The value of 2 is rarely found theoretically. Rb will be changing from one order to another because of the possibility of variations in subwatershed geometry and lithology, but tends to be constant throughout the series. Analysis of the result shown in Table 5 shows the mean bifurcation ratio of the 17 subwatersheds.

Bifurcation ratio does not precisely remain constant from one order to the next, because of possibility of variations in subwatershed geometry and lithology, but it tends to be a constant throughout the series. High Rb indicates early hydrograph peak with a potential for flash flooding during the storm events. Also Rb is very much controlled by basin shape and shows a very little variation (ranging between 3 and 5) in homogeneous bedrock from one area to another and if Rb is greater than 5, then the basin is elongated and geological structure control the basin. Maximum Rb is found in W17, thus it will show early hydrograph peak (smaller basin lag time) which also indicates strong structural control on the drainage development for this subwatersheds. The minimum Rb is observed in W5, indicating delayed hydrograph peak. It is found that the rock type is homogenous in eight watersheds namely, W3, W4, W5, W10, W12, W14, W15 and W16. The basin is elongated and geological structure controls the basin in nine watersheds namely W1, W2, W6, W7, W8, W9, W11, W13 and W17.

Table-5: Showing bifurcation ratios of watersheds

Subwatershed	Mean Bifurcation Ratio
W1	5.6
W2	5.3
W3	4.5
W4	4.2
W5	4.0
W6	5.3
W7	5.8
W8	6.2
W9	5.6
W10	4.3
W11	6.9
W12	4.8
W13	6.2
W14	4.1
W15	4.2
W16	4.6
W17	7.1

4) Drainage Density (Dd)

It is the sum of the channel lengths per unit area and obtained by dividing the total stream length by total area of the basin. It is controlled by the type of formations in the basin areas with impervious formations will have higher drainage density than those with pervious formations. It is found that low drainage density is favoured in regions of high resistant or highly permeable sub soil materials, under dense vegetation cover and where relief is low. High drainage density is favoured in regions of weak or impermeable surface materials, sparse vegetation, and mountainous relief. The drainage density is governed by the factors like rock type, run off intensity, soil type, infiltration capacity and percentage of rocky area. In this study area the Dd is less in all the subwatersheds as shown in Table 6 hence the study area comes under permeable sub soil materials.

5) Stream Frequency (Fs)

It is the number of streams segment per unit area and relates to the importance to ground water recharge characteristics in a river basin. The analysis of the result is as shown in Table 6 which shows that Fs is maximum and minimum in subwatershed W9 (3.35/km2) and W16 (2.45/km2) respectively. Fs is related to permeability and infiltration capacity. The values observed in the district that W9 is having rocky terrain and very low infiltration capacity out of the 17 subwatersheds. Fs of W16, indicates that the subwatershed is comparably covered with good amount of vegetation and has very good infiltration capacity.

6) Drainage Texture

It is influenced by infiltration capacity. There are five different texture classes: very coarse (<2), coarse (2–4), moderate (4–6), fine (6–8), and very fine (>8). As per the classification, W16 has course drainage texture, W1, W2, W3, W4, W5, W6, W7, W8, W10, W11, W12, W13, W14, W15 and W17 have moderate drainage texture and W9 is having fine drainage texture (Table 6). Hydrologically very coarse texture subwatershed have large basin lag time periods followed by coarse, moderate, fine, and very fine texture classes. Hence this indicates that W16 (3.94) shows longer duration to peak flow and W9 (6.32) shows the shortest.

7) Form Factor (Rf)

It is the ratio of the basin area to the square of the basin length is called form factor. It is used as a quantitative expression on the shape of the basin form. If form factor is less than 5, then it is a flattered and flows for longer duration and if the value is greater than 5, then it is having high peaks and flows for short duration. In this study, W3, W4, W8, W10, W13, W14 and W15 show lower form factor (Table 6) indicating elongated shape and suggesting flat hydrograph peak for longer duration. Flood flows of such elongated basins are easier to manage than those of the circular basin. W7, W9 and W11 have slightly circular shape as suggested by moderately higher Rf. Subwatersheds W1, W2, W5, W6, W12, W16 and W17 have high Rf indicating that they have developed into quite circular shape.

8) Elongation Ratio (Re)

It is the ratio of diameter of the circle of the same area in the basin to the maximum basin length. If the ratio is high, then lesser will be flood peak. This ratio varies between 0.6 to 1.0 over wide variety of climatic and geological formations. Values in the range of 0.6 to 0.8 are generally associated with strong relief and steep ground slope, whereas values nearing 1.0 are typical of very low relief. The high elongated ratio suggests that the basins are more elongated. These values can be classified into three categories, namely, circular (>0.9), oval (0.9–0.7), and less elongated (<0.7). Re for the subwatersheds W3, W8, W10, W13, W14 and W15 is less than 0.70 which indicates that subwatersheds are elongated with high relief and steep slope. W4, W7, W9 and W11 subwatersheds fall in oval category, while subwatersheds W1, W2, W5, W6, W12, W16 and W17 fall in the circular category (Table 6). The circular subwatersheds have fast, though lower hydrograph peak compared to the oval and elongated subwatersheds. This indicates that W8 will show delayed time to peak flow, while W6 will show shorter time to peak.

Table-6: Showing important morphometric parameters of the watersheds

Subwatershed	Drainage Density (Dd) in km/km^2	Stream Frequency (Fs) per km^2	Drainage Texture	Form Factor	Elongation Ratio
W1	1.76	3.02	5.33	0.90	1.07
W2	1.62	3.06	4.97	0.67	0.92
W3	1.89	2.93	5.53	0.21	0.52
W4	1.84	3.20	5.89	0.21	0.74
W5	1.90	3.04	5.78	0.81	1.01
W6	1.89	2.64	4.98	2.44	1.76
W7	1.68	3.13	5.27	0.59	0.87
W8	1.72	2.97	5.09	0.17	0.46
W9	1.89	3.35	6.32	0.40	0.71
W10	1.97	2.91	5.73	0.31	0.63
W11	1.73	3.03	5.22	0.63	0.89
W12	1.57	2.72	4.27	0.71	0.95
W13	1.74	2.82	4.89	0.38	0.70
W14	1.91	2.89	5.53	0.20	0.51
W15	1.65	3.11	5.13	0.25	0.56
W16	1.61	2.45	3.94	1.46	1.36
W17	1.65	2.99	4.92	0.85	1.04

IV. CONCLUSION

From the integrated morphometry analysis of the 17 subwatersheds, it is concluded that the whole study area has uniform lithology and structurally permeable. The spatial variation of the morphometric parameters which are analyzed in this study is quite significant. As the hydrology of the study area changes significantly due to the spatial variability of the morphometric parameters, the subwatersheds will therefore also exhibit differential hydrological behaviour. The overall result indicates that W5, W12 and W16 subwatersheds have small basin lag time periods and attain early hydrograph peak and on the contrary, W8 and W13 subwatersheds have longer duration for the peak flow. The hydrological behaviour of these 17 subwatersheds have been discussed in the result section and it concludes that the study area is highly permeable subsoil materials, homogenous rock type, low runoff zone with good vegetation cover and low relief. The study gives assistance in watershed development and its management.

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