

Morphometric Studies of Fourth order Sub-Basins (FOSB's) in North Bangalore Metropolitan Region using Remote Sensing and Geographic Information System Techniques

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Abstract: The quantitative analysis of drainage system is an important aspect of characterization of watersheds. Using watershed as a basic unit in morphometric analysis is the most logical choice because all hydrologic and geomorphic processes occur within the watershed. The North Bangalore Metropolitan Region is constitutes a part of North Pennar, South Pennar and Cauvery Basins has been selected for the case illustration. Geo-informatics module consists of GIS mapping for location map, drainage map, surface water body map, sub-basin map etc are generated. Morphometric module consists of morphometric analysis for several drainage basin parameters include stream order, stream length, bifurcation ratio, drainage density, drainage frequency, form factor, elongation ratio, circularity ratio, texture ratio, length of overland flow and constant of channel maintenance are also calculated. An attempt has been made to utilize the interpretation capabilities of GIS to find out the relationship between the morphometric parameters at sub basin level.

Keywords: Bangalore Metropolitan Region; Sub-basin; Geographic Information System; Morphometric Parameters.

I. Introduction

Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms^{[1][7]}. River basins comprise a distinct morphologic region and have special relevance to drainage pattern and geomorphology^[13]. Horton's law of stream lengths suggests a geometric relationship between the number of stream segments in successive stream orders and landforms^[3]. Quantitative description of the basin morphometry also requires the characterization of linear and areal features, gradient of channel network and contributing ground slopes of the drainage basin. Detailed analysis of drainage parameters is of great help in understanding the influence of drainage morphometry on landforms and their characteristics. Geographic Information System techniques have been adopted for the identification of morphological features and analyzing their properties of Fourth order Sub-Basins (FOSB's) in North Bangalore Metropolitan Region, Karnataka state, India.

II. Materials and Methods

a. Study Area

The study area encompasses a geographical area of 4,665 km² (Figure 1.1) between 800 m and 1800 m altitude above mean sea level and the study area lies between latitude 12.50°N to 13.30°N and longitude 77.00°E to 78.10°E in Survey of India (1:50,000) toposheet No. 57G/4, 57G/7, 57G/8, 57G/11, 57G/12, 57G/15, 57G/16, 57H/1, 57H/5, 57H/9 and 57H/13.

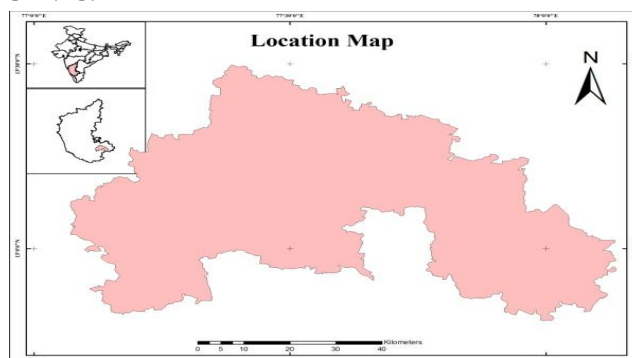


Figure 1.1: Location Map of North Bangalore Metropolitan Region

b. Methodology: The study comprises mainly two components:

GIS Mapping: The necessary base maps for morphometric analysis carried out through GIS Mapping using SOI Topographical Sheets of the area at scale 1:50,000. The required GIS maps are location map, drainage map, surface water body map, drainage order map, drainage sub-watershed map.

Morphometric Analysis: The morphometric parameters are calculated^{[3][13][10][1]}. Morphometric parameters like stream order, stream length, bifurcation ratio, drainage density, drainage frequency, texture ratio, elongation ratio, circularity ratio, form factor, length of overland flow and constant of channel maintenance are calculated.

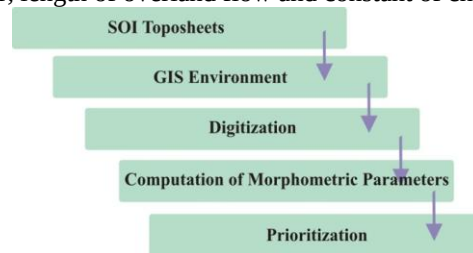


Table 1.1: Methods of calculating morphometric parameters

	Morphometric Parameters	Methods	References
LINEAR	Stream order (U)	Hierarchical order	Strahler, 1964
	Stream length (Lu)	Length of the stream	Horton, 1945
	Mean stream length (Lsm)	$Lsm = Lu/Nu$; where, Lu =Stream length of order 'U' Nu =Total number of stream segments of order 'U'	Horton, 1945
	Stream length ratio (Rl)	$Rl = Lu/Lu-1$; where Lu =Total stream length of order 'U', $Lu-1$ =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
ARIAL	Drainage density (Dd)	$Dd = L/A$ where, L =Total length of streams; A =Area of watershed	Horton, 1945
	Stream frequency (Fs)	$Fs = N/A$; where, N =Total number of streams; A =Area of watershed	Horton, 1945
	Texture ratio (T)	$T = N1/P$; where, $N1$ =Total number of first order streams; P =Perimeter of watershed	Horton, 1945
	Form factor (Rf)	$Rf = A/(Lb)^2$; where, A =Area of watershed, Lb =Basin length	Horton, 1932
	Circulatory ratio (Rc)	$Rc = 4\pi A/P^2$; where, A =Area of watershed, $\pi=3.14$, P =Perimeter of watershed	Miller, 1953
	Elongation ratio (Re)	$Re = 2\sqrt{(A/\pi)}/Lb$; where, A =Area of watershed, $\pi=3.14$, Lb =Basin length	Schumn,1956
	Length of overland flow (Lof)	$Lof = 1/2Dd$; where, Dd =Drainage density	Horton, 1945
	Constant of channel maintenance (C)	$C = 1/Dd$; where, Dd =Drainage density	Schumn,1956
	Compactness ratio (Cc)	$Cc = 0.2821 * P/A^{0.5}$; where, P =Perimeter of the basin(km), A =Area of the basin (km ²)	Horton, 1945

III. Results and Discussion

a. Stream Order (N_u): The streams of the study area have been ranked^[13]; when two first order streams join, a stream segment of second order is formed; When two second order streams join, a segment of third order is formed, and so on. In the present studies Fourth Order Sub-Basins (FOSBs) are delineated for morphometric analysis.

Figure 1.2: Drainage Map of Study area

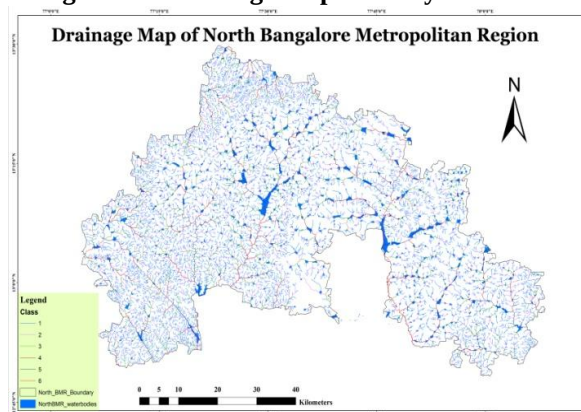
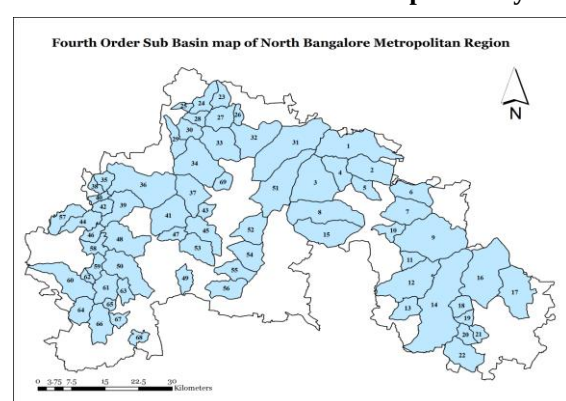


Figure 1.3: Fourth Order Sub-Basin Map of Study area



b. Stream Length (L_u) & Mean Stream Length: The stream length of various orders has been measured from ArcGIS Software. Horton's law^[3] of stream length supports the theory that geometrical similarity is preserved generally in the basins of increasing order^[13]. The mean length of channel L_u of order U is the ratio of the total

length to the number of streams of a given order. Mean length of channel segments of a given order is greater than that of the next lower order but less than that of the next higher order.

c. Bifurcation Ratio (R_b): Bifurcation Ratio is the ratio of the number of streams of an order to the number of streams of the next higher order^[3]^[13].

$$R_b = N_u / N_{u+1}$$

Where, N_u = Total number of stream segment of order 'u';

N_{u+1} = Number of segment of next higher order

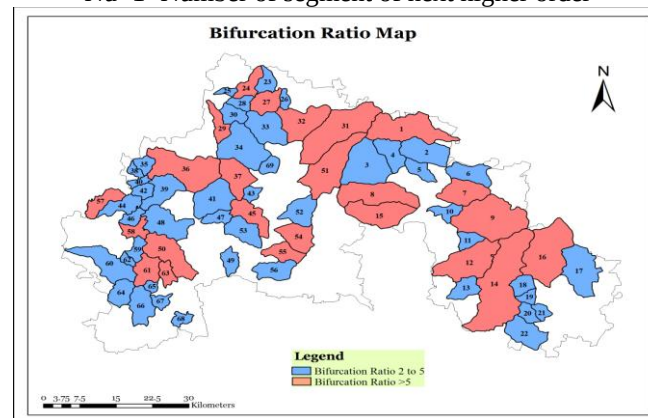


Figure 1.4: Bifurcation Ratio Map

Bifurcation ratios are related to the structural control on the drainage^[13]. There are 45 numbers of Fourth Order Sub-Basins (FOSBs) are ranges the R_b of 2 to 5 and 24 numbers of Fourth Order Sub-Basins (FOSBs) are ranges the R_b of more than 5. A lower R_b range between 3 to 5 suggests that structure does not exercise a dominant influence on the drainage pattern. Higher R_b greater than 5 indicates some sort of geological control^[1]. If the R_b is low, the basin produces a sharp peak in discharge and if it is high, the basin yields low, but extended peak flow^[1]. In well developed drainage network the bifurcation ratio is generally between 2 to 5^[3]^[13].

d. Drainage density (D_d): The drainage density^[3] is an important indicator of the linear scale of landform elements in stream eroded topography. It is the ratio of total channel segment lengths cumulated for all orders within a basin to the basin area, which is expressed in terms of mi/sq.mi or km/sq.km. The drainage density indicates the closeness of spacing of channels, thus providing a quantitative measure of the average length of stream channel for the whole basin. It has been observed from drainage density measurements made over a wide range of geologic and climatic types that a low drainage density is more likely to occur in regions of highly resistant or highly permeable subsoil material under dense vegetative cover, and where relief is low. 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^[13]. The measurement of D_d is a useful numerical measure of landscape dissection and runoff potential^[2]. On the one hand, the D_d 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^[9]. D_d is known to vary with climate and vegetation^[6], soil and rock properties^[4], relief^[8] and landscape evolution processes. The D_d of the study area varies from 1.09 kms/ km² and 2.98 kms/ km² in 14th and 62nd Fourth Order Sub-Basin (FOSB) respectively. The Fourth Order Sub-Basins (FOSBs) can be grouped into three categories on the basis of D_d as Low (below 2.0 kms/km²), Moderate (2.0-2.5 kms/km²) and High (2.5-3.0 kms/km²). The drainage density of FOSBs in the study area are varies from 1.09 to 2.98. Whereas the 41 FOSBs having Low D_d (below 2.0 kms/km²), 20 FOSBs contains Moderate D_d (2.0-2.5 kms/km²) and 08 FOSBs results the High D_d (2.5-3.0 kms/km²).

e. Stream frequency/Drainage frequency (D_f): It is defined as the total number of stream segments of all orders per unit area^[3]. It is an index of the various stages of landscape evolution. The occurrence of stream segments depends on the nature and structure of rocks, vegetation cover, nature and amount of rainfall and soil permeability.

Thus it has been possible to identify three categories of D_f ; Low (below 2.5/km²), Moderate (2.5-3.5/km²) and High (Above 3.5/km²). The drainage frequency of FOSBs in the study area are varies from 0.89 to 4.77. Whereas the 41 numbers of FOSBs having Low D_f (below 2.5/km²), 19 numbers of FOSBs contains Moderate D_f (2.5-3.5/km²) and 09 numbers of FOSBs results the High D_f (>3.5 /km²).

f. Circularity ratio (R_c): The circularity ratio is the ratio of the area of the basin to the area of a circle having the same circumference as the perimeter of the basin^[5]. It is a significant ratio, which indicates the dendritic stage of a Sub-Basin. Its low, medium and high values are indicative of the youth, mature and old stages of the life cycle of the tributary basins. The high value of the ratio is more influenced by length, frequency and gradient of streams of various orders and further depends on the geological structures, land use/land cover, climate, relief and slope of the basin.

In the present study, the circularity ratio ranges from 0.34 to 0.81. High circularity ratio is observed in 45 numbers of FOSBs indicate that they are more or less circular in shape and are characterized by high to moderate relief and drainage system is not structurally controlled. The remaining 24 numbers of FOSBs have less than 0.5 indicating that they are elongated in shape.

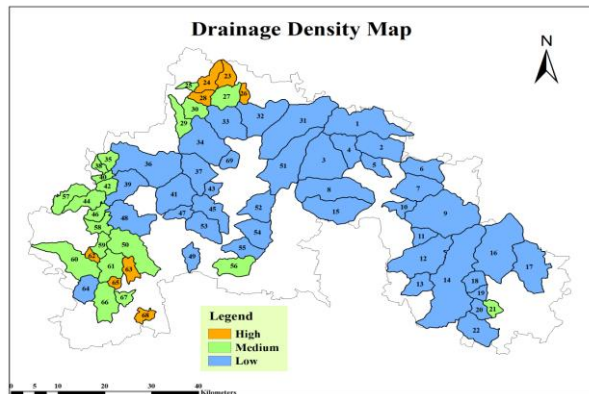


Figure 1.5: Drainage Density Map

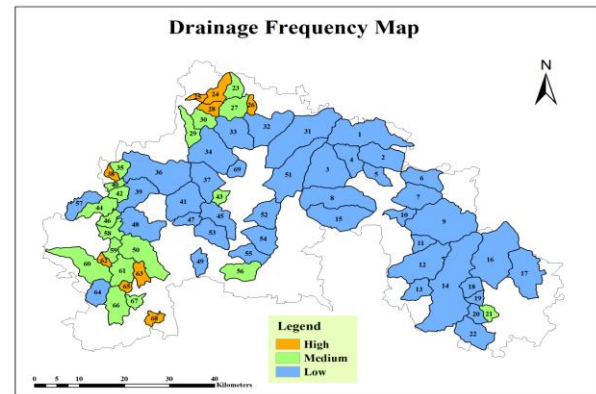


Figure 1.6: Drainage Frequency Map

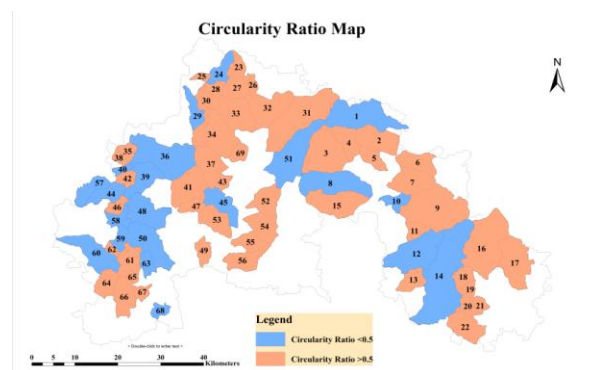


Figure 1.7: Circularity Ratio Map

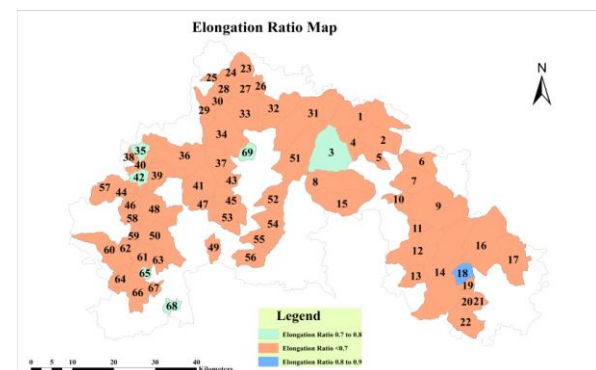


Figure 1.8: Elongation Ratio Map

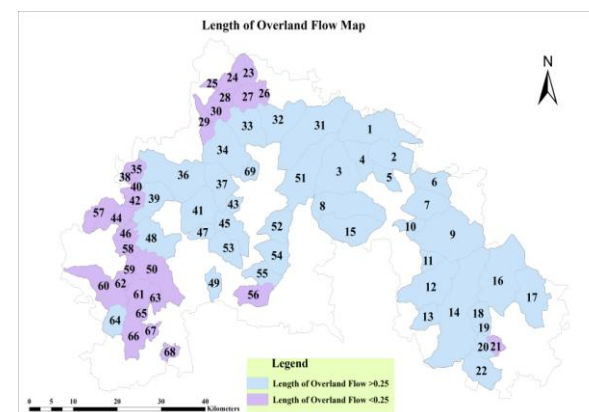


Figure 1.9: Length of Overland Flow Map

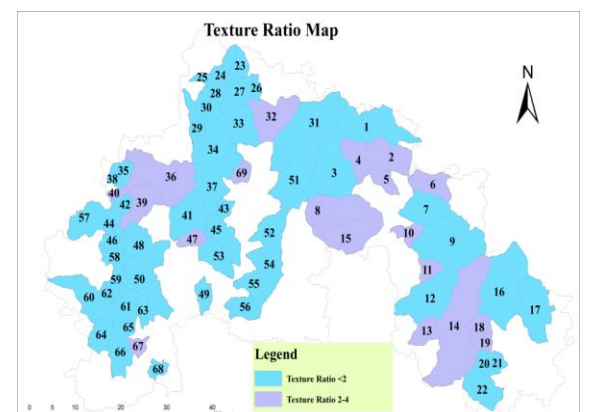


Figure 1.10: Texture Ratio Map

g. Texture Ratio (T): Texture ratio is the total number of stream segments of all orders per perimeter of that area^[3]. It is one of the important concepts of geomorphology which means that the relative spacing of drainage lines. Drainage lines are numerous over impermeable areas than permeable areas. Infiltration capacity^[3] as the

single important factors which influences texture ratio and considered texture ratio which includes drainage density and stream frequency. The values of texture ratio of the study area vary from 1.26 to 3.96. Five different texture^[12] ratios have been classified based on the drainage density. The texture ratio less than 2 indicates very coarse, between 2 to 4 is related to coarse, between 4 to 6 is moderate, between 6 to 8 is fine and greater than 8 is very fine texture ratio. Wherein the study area, 19 numbers of FOSBs having less than 2 indicate very coarse and 50 numbers of FOSBs having 2 to 4 is related to coarse drainage texture ratio.

h. Form Factor (F_f): Form factor is defined as the ratio of basin area to square of the basin length^[3]. The value of form factor would always be greater than 0.78 for a perfectly circular basin. Smaller the value of form factor, more elongated will be the basin. It is noted that the F_f values vary from 0.13 to 0.51 and all the FOSBs indicate that they are sub-circular and elongated.

i. Elongation Ratio (R_e): Elongation ratio^[10] is the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin. Analysis of elongation ratio indicates that the areas with higher elongation ratio values have high infiltration capacity and low runoff. A circular basin is more efficient in the discharge of runoff than an elongated basin^[11]. The elongation ratio and shape of basin are given in Table 1.2.

Table 1.2: Elongation ratio and shape of river

Elongation ratio	Shape of basin
<0.7	Elongated
0.7-0.8	Less elongated
0.8-0.9	Oval
>0.9	Circular

The Elongation ratio of the study area shows 62 numbers of FOSBs having <0.7, 6 numbers of FOSBs having 0.7-0.8 and one FOSB having 0.8-0.9 Elongation ratio. The results indicate that the 62, 06 and 01 number of FOSBs are having elongated, less elongated and oval shape respectively.

j. Length of Overland Flow (L_g): It is the length of water over the ground before it gets concentrated in to definite streams channels^[3]. This factor depends on the rock type, permeability, climatic regime, vegetation cover and relief as well as duration of erosion^[10]. The length of overland flow approximately equals to half of the reciprocal of drainage density^[3]. In the study area, it is observed that the length of overland flow varies from 0.16 to 0.45. It indicates that 28 numbers of FOSBs having length of overland flow from 0.16 to 0.25 may be under the influence of high structural disturbance, low permeability, steep to very steep slopes and high surface runoff. Other remaining 41 numbers of FOSBs having length of overland flow greater than 0.25 are under very less structural disturbance, less runoff conditions and having higher overland flow. A larger value of length of overland flow indicates longer flow path and thus, gentler slopes.

k. Constant of Channel Maintenance (C): Introduced the factor, constant of channel maintenance, as the inverse of drainage density^[10]. It is also the area required to maintain one linear kilometer of stream channel. Generally, a higher constant of channel maintenance of a basin indicates higher permeability of rocks of that basin, and vice versa. This means, 0.34 km² is required to maintain one kilometer of stream channel. From this study, it is inferred that the 25 numbers of FOSBs are required more than 0.6 Km² area to maintain one kilometer length stream channel, which in turn indicates that these FOSBs are comparatively permeable than remaining sub basins.

l. Compactness Ratio (C_c): Compactness Ratio is defined as the ratio between the area of the basin and the perimeter of the basin.

Table 1.3: Morphometric parameters of Fourth Order Sub Basins (FOSBs)

Fourth Order Sub-basin No	Sub-basin Area (Km ²)	Perimeter (Km.)	Drainage Density (Km/Sq Km.)	Drainage frequency (Streams/Sq km.)	Circularity Ratio (R_c)	Texture Ratio (T)	Length of overland flow (L_g)	Basin Length (Lb in km)	Form factor (F_f)	Elongation Ratio (R_e)	Compactness constant (C_c)	Constant of Channel Maintenance (C)
1	89.36	53.35	1.30	1.20	0.39	2.01	0.38	22.72	0.17	0.47	0.218	0.77
2	50.366	30.36	1.10	1.07	0.69	1.78	0.46	12.94	0.30	0.62	0.219	0.91
3	82.638	39.06	1.14	0.96	0.68	2.02	0.44	13.38	0.46	0.77	0.194	0.88
4	32.679	27.23	1.49	1.47	0.55	1.76	0.34	10.97	0.27	0.59	0.258	0.67
5	20.211	21.13	1.50	1.83	0.57	1.75	0.33	9.54	0.22	0.53	0.288	0.67
6	35.218	28.84	1.67	1.59	0.53	1.94	0.30	12.5	0.23	0.54	0.255	0.60
7	48.469	30.25	1.81	1.92	0.67	3.07	0.28	14.76	0.22	0.53	0.223	0.55

8	76.359	45.73	1.19	1.13	0.46	1.88	0.42	20.43	0.18	0.48	0.218	0.84
9	119.361	47.84	1.38	1.35	0.66	3.37	0.36	20.88	0.27	0.59	0.179	0.73
10	17.747	22.71	1.78	2.08	0.43	1.63	0.28	9.24	0.21	0.51	0.319	0.56
11	16.54	18.08	1.26	1.45	0.64	1.33	0.40	6.84	0.35	0.67	0.295	0.80
12	82.566	45.95	1.44	1.55	0.49	2.79	0.35	21.13	0.18	0.49	0.210	0.70
13	24.879	22.06	1.32	1.13	0.64	1.27	0.38	9.17	0.30	0.61	0.266	0.76
14	173.474	78.29	1.09	0.89	0.36	1.97	0.46	32.26	0.17	0.46	0.190	0.92
15	65.017	38.16	1.21	1.03	0.56	1.76	0.41	16.42	0.24	0.55	0.216	0.82
16	112.503	49.27	1.31	1.20	0.58	2.74	0.38	19.68	0.29	0.61	0.187	0.77
17	69.768	40.79	1.52	1.46	0.53	2.50	0.33	16.27	0.26	0.58	0.216	0.66
18	18.84	18.07	1.28	1.27	0.72	1.33	0.39	6.06	0.51	0.81	0.276	0.78
19	10.249	14.26	1.54	1.95	0.63	1.40	0.32	5.84	0.30	0.62	0.333	0.65
20	14.644	16.895	1.95	2.46	0.64	2.13	0.26	6.79	0.32	0.64	0.303	0.51
21	10.157	14.34	2.11	2.95	0.62	2.09	0.24	5.56	0.33	0.65	0.335	0.47
22	43.43	29.01	1.92	2.10	0.65	3.14	0.26	11.07	0.35	0.67	0.231	0.52
23	18.407	20.99	2.51	3.10	0.52	2.72	0.20	9.33	0.21	0.52	0.301	0.40
24	23.122	25.86	2.56	3.76	0.43	3.36	0.20	11.53	0.17	0.47	0.298	0.39
25	6.528	12.759	2.48	3.98	0.50	2.04	0.20	5.59	0.21	0.52	0.394	0.40
26	8.57	13.29	2.76	4.08	0.61	2.63	0.18	5.63	0.27	0.59	0.351	0.36
27	29.858	23.97	2.49	3.18	0.65	3.96	0.20	10.55	0.27	0.58	0.253	0.40
28	13.637	17.221	2.65	3.89	0.58	3.08	0.19	7.22	0.26	0.58	0.317	0.38
29	22.584	27.48	2.38	3.10	0.38	2.55	0.21	12.6	0.14	0.43	0.311	0.42
30	20.568	19.86	2.17	2.92	0.65	3.02	0.23	8.07	0.32	0.63	0.277	0.46
31	114.592	53.31	1.31	1.15	0.51	2.48	0.38	26.48	0.16	0.46	0.192	0.76
32	62.003	37.67	1.21	1.00	0.55	1.65	0.41	14.45	0.30	0.62	0.220	0.83
33	53.799	32.24	1.50	1.60	0.65	2.67	0.33	12.4	0.35	0.67	0.218	0.67
34	76.253	39.73	1.32	1.25	0.61	2.39	0.38	15.3	0.33	0.64	0.204	0.76
35	13.546	15.948	2.41	3.47	0.67	2.95	0.21	5.83	0.40	0.71	0.306	0.42
36	99.5	51.82	1.20	0.93	0.47	1.79	0.42	16.56	0.36	0.68	0.204	0.83
37	45.982	30.79	1.51	1.50	0.61	2.24	0.33	11.47	0.35	0.67	0.231	0.66
38	7.579	13.58	2.48	3.96	0.52	2.21	0.20	5.43	0.26	0.57	0.378	0.40
39	41.098	33.46	1.52	1.48	0.46	1.82	0.33	13.53	0.22	0.53	0.255	0.66
40	7.542	14.22	2.34	3.31	0.47	1.76	0.21	5.1	0.29	0.61	0.387	0.43
41	56.613	32.28	1.59	1.55	0.68	2.73	0.32	13.65	0.30	0.62	0.213	0.63
42	13.488	15.525	2.11	2.74	0.70	2.38	0.24	5.27	0.49	0.79	0.303	0.47
43	10.849	14.19	1.89	2.77	0.68	2.11	0.26	5.48	0.36	0.68	0.323	0.53
44	27.835	29.7	2.35	3.02	0.40	2.83	0.21	12.69	0.17	0.47	0.291	0.42
45	32.229	33.23	2.00	2.11	0.37	2.05	0.25	14.87	0.15	0.43	0.286	0.50
46	13.66	18.404	2.43	3.22	0.51	2.39	0.21	7.16	0.27	0.58	0.327	0.41
47	15.913	18.666	1.68	2.14	0.57	1.82	0.30	7.98	0.25	0.56	0.306	0.59
48	54.968	39.23	1.83	2.00	0.45	2.80	0.27	14.31	0.27	0.58	0.238	0.55
49	17.898	19.705	1.92	2.46	0.58	2.23	0.26	8.27	0.26	0.58	0.296	0.52
50	62.053	41.97	2.22	2.59	0.44	3.84	0.22	17.81	0.20	0.50	0.232	0.45
51	88.777	51.02	1.40	1.37	0.43	2.39	0.36	21.8	0.19	0.49	0.214	0.71
52	36.358	27.35	1.71	1.87	0.61	2.49	0.29	11.76	0.26	0.58	0.245	0.58
53	36.394	26.81	1.74	1.70	0.64	2.31	0.29	11.7	0.27	0.58	0.242	0.58
54	37.998	26.7	1.85	2.05	0.67	2.92	0.27	10.91	0.32	0.64	0.236	0.54
55	26.746	24.95	1.94	2.36	0.54	2.53	0.26	11.27	0.21	0.52	0.272	0.52
56	32.094	26.08	2.07	2.59	0.59	3.18	0.24	10.62	0.28	0.60	0.254	0.48
57	27.43	28.91	2.06	2.19	0.41	2.08	0.24	11.28	0.22	0.52	0.290	0.49
58	18.573	25.97	2.36	3.12	0.35	2.23	0.21	9.42	0.21	0.52	0.334	0.42
59	14.921	19.37	2.12	2.61	0.50	2.01	0.24	7.51	0.26	0.58	0.321	0.47
60	57.12	42.6	2.18	2.52	0.40	3.38	0.23	20.41	0.14	0.42	0.244	0.46
61	32.596	27.41	2.17	2.79	0.54	3.32	0.23	9.38	0.37	0.69	0.259	0.46
62	6.504	11.7787	2.98	4.77	0.59	2.63	0.17	4.86	0.28	0.59	0.380	0.34
63	15.876	20.122	2.83	4.03	0.49	3.18	0.18	7.55	0.28	0.60	0.318	0.35
64	26.457	21.2	1.70	2.08	0.74	2.59	0.29	10.06	0.26	0.58	0.253	0.59
65	6.651	10.42	2.67	4.66	0.77	2.98	0.19	4.06	0.40	0.72	0.353	0.37
66	38.81	29.2	2.06	2.78	0.57	3.70	0.24	12.39	0.25	0.57	0.245	0.49
67	10.998	16.153	2.10	2.82	0.53	1.92	0.24	6.45	0.26	0.58	0.342	0.48
68	11.038	16.866	2.93	4.44	0.49	2.91	0.17	5.21	0.41	0.72	0.349	0.34
69	13.998	14.679	1.70	2.00	0.82	1.91	0.29	5.57	0.45	0.76	0.289	0.59

IV. Conclusion

Remote sensing and GIS techniques have proved to be efficient tools in drainage delineation and their updation. These updated drainages have been used for the morphometric analysis. The morphometric analysis was carried out through measurement of linear, areal and relief aspects of basins. The morphometric analysis of the drainage networks of the sub-basins of the study area show dendritic to sub-dendritic patterns with moderate drainage texture. The variation in stream length ratio might be due to change in

slope and topography. The bifurcation ratio in 45 sub-basins indicates structure doesn't exercise a dominant influence and produces sharp peak and 24 sub-basins indicates some sort of geological control, these basins yields low, but extended peak flow and the presence of low drainage density in 41 sub-basins suggesting that it has highly permeable sub-soil and coarse drainage texture. High circularity ratio is observed in 45 FOSBs indicate that they are more or less circular in shape and are characterized by high to moderate relief and drainage system is not structurally controlled and the remaining 24 sub basins indicating that they are elongated in shape. Texture ratio indicates 19 sub basins having very coarse and 50 numbers of FOSBs having related to coarse drainage texture ratio. The values of form factor suggest that all the FOSBs are sub-circular and elongated. Elongation ratio indicates that the 62 sub-basins are region of very low relief whereas other sub-basins are associated with moderate to high relief and steep ground slopes. Length of overland flow indicates that 28 numbers of FOSBs influence of high structural disturbance, low permeability, steep to very steep slopes and high surface runoff and the remaining 41 sub basins having very less structural disturbance, less runoff conditions and having higher overland flow. Constant of Channel Maintenance indicates that 25 sub basins are required more than 0.6 Km² area to maintain one kilometer length stream channel, which in turn indicates that these sub basins are comparatively permeable than remaining sub basins.

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