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Morphometric analysis and watershed prioritisation: a case study of Kabani river basin, Wayanad district, Kerala, India

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Kabani river is a 7th order stream with a basin area of 1647 km^2. There are 4 sixth order and11 fifth order sub-basins. This analysis is mainly confined to 11 fifth order sub basins. Morphometric indices like stream ordering, bifurcation ratio, stream length, drainage density, stream frequency, form factor, elongation ratio, circularity ratio, constant of channel maintenance, asymmetry factor, sinuosity index, length of overland flow, drainage texture, relief ratio and relative relief have been worked out for all these 11 fifth order sub basins. Factors considered for watershed prioritisation are: bifurcation ratio, drainage density, stream frequency, drainage texture, form factor, circularity ratio, elongation ratio and relative relief. Sub watershed like Ws_1, Ws_3, Ws_4, Ws_{10} and Ws_{11} showing low compound parameter are suggested for conservation treatment.

[**Keywords:** Morphometry, Drainage basin, Quantitative analysis, Watershed Prioritisation]

Introduction

Drainage basin is a basic unit in morphometric analysis because all the hydrologic and geomorphic processes occur within the watershed where denudational and aggradational processes are most explicitly manifested[1-2]. The term 'morphometry' literally means measurement of forms Horton[3] introduced the quantitative description for landforms. Horton's work has been subsequently modified and developed by Schumm[4] and Strahler[5]. Mesa[6] done morphometric analysis to determine the drainage character and Rapisarda[7] used this study for landsliding analysis.

Sharma and Padmaja[8] and Singh and Upadhyay[9] have applied and tested morphometry analysis in different part of the country. Recently, Nag[10], Zaidi[11] are using remote sensing and GIS techniques for morphometric analysis. In Kerala, number of studies has been carried out in this field (Sinha Roy[12], Samsudeen[13], Rajendran[14], Mahamaya[15]). Mahamaya[2] has studied the morphometric character of periyar river basin. A systematic morphometric analysis helps understand linear, areal and relief aspects of the drainage basin. In the present study our attempt is to use morphometric indices for prioritisation of watershed for conservation and management.

The east flowing Kabani river, a tributary of Cauvery river system has been selected for this study. (Figs 1 & 2) Kabani is a seventh order stream, with a catchment area of 1647 km^2. Basin is situated in the Wayanad plateau region and mostly circular in nature.

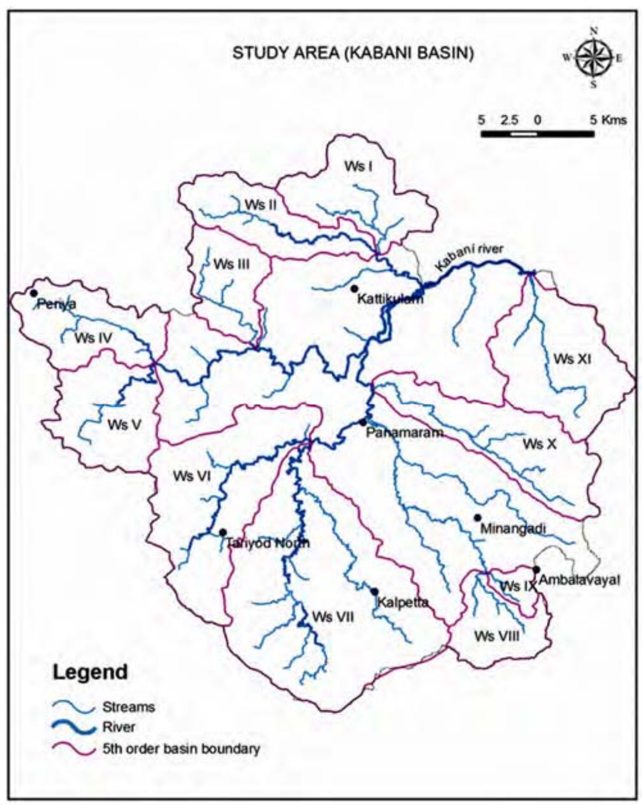

Fig. 1—Location map

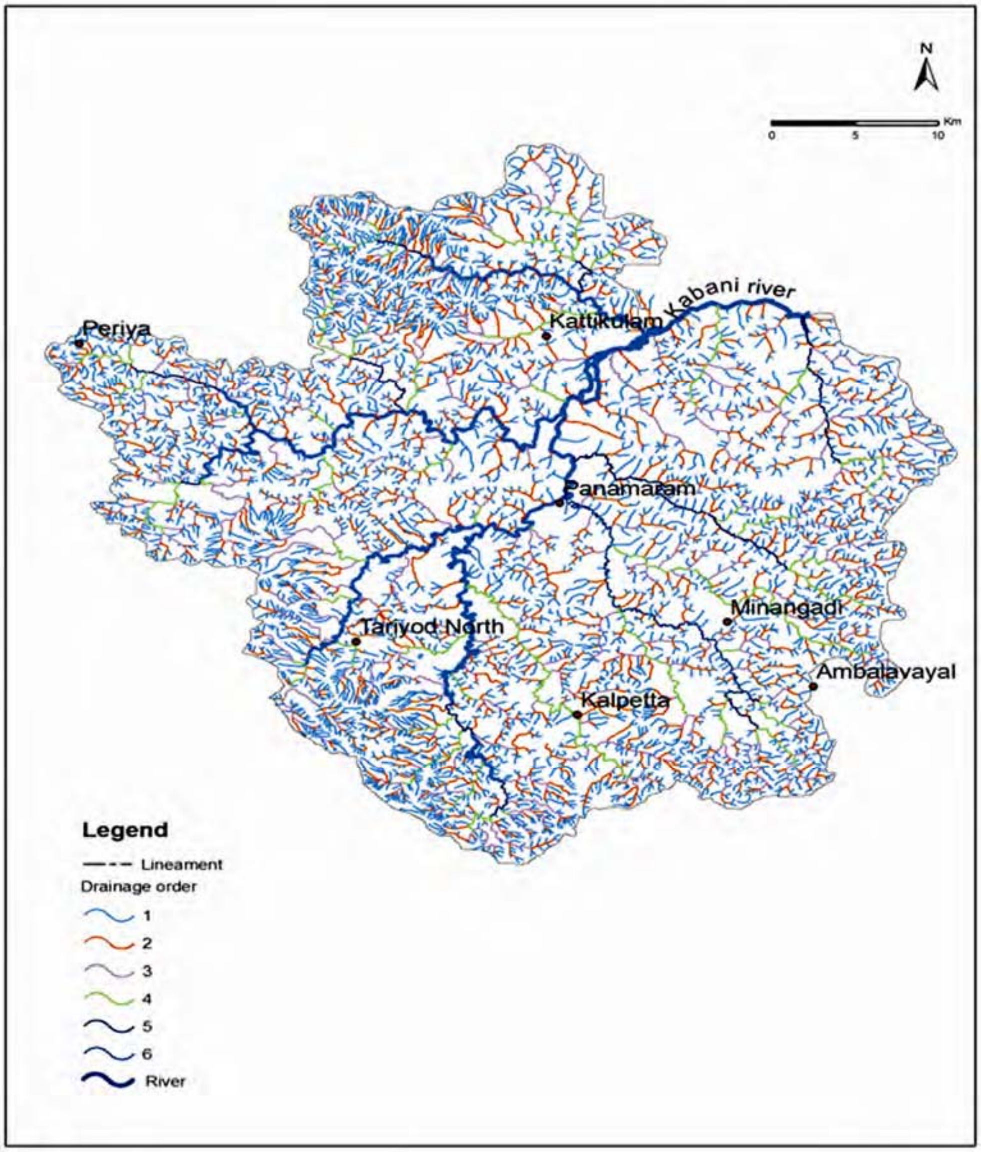

Fig. 2—Drainage map

This plateau surface has a general slope towards east and north east and merges with the Mysore plateau. Elevation of this plateau ranges between 700-2059 m above MSL. More than 85% of the area lie within 700 m to 900 m[16] Lithologically the plateau is made up of meta volcanics, metasediments and igneous rocks. Most of the stream courses are controlled by structural features such as fault, fracture and schistocity planes[18]. Bavali fault running NW-SE is the most conspicuous structural feature in this area. On an average; this area receives around 3,500 mm of rainfall, 75 per cent of which precipitates during south-west monsoon[17]. It is observed that paddy is being cultivated as a dominant crop in the broad valley of the Kabani river. Plantation crops like coffee, rubber, tea etc. also dominate here. The whole area presented complex scenario of structurally controlled denudational hills with intervening valley plain. Drainage is quite often deeply incised over the dissected plateau with broad and flat valley floor commonly filled with slope wash material (ie.colluviam) and alluvium[18]. Present work is an attempt to compute morphometric indices of 11 fifth and 4 sixth order sub basins under the Kabani river and prioritise them for conservation. Basin morphometry includes analysis and characteristics of linear, areal and relief aspects of fluvially originated drainage basin.

Materials and Methods

Survey of India topographical maps of 1:50,000 scale provided the base material. Entire basin is divided into 4 sixth order and 11 fifth order sub basins for quantitative analysis. Drainage channels were ordered according to Strahler's classification[5]. All maps are prepared by using Arch GIS software and spatial interrelations were studied.

Results and Discussion

Linear aspects

Linear aspects of the basins are related to the channel pattern of the drainage network, where in the topological characteristics of the stream segments in terms of open links of the network system (Stream) are analysed. Linear aspect of the basin includes the analysis of stream order (Nu), Bifurcation Ratio (Rb), Stream Length (Lu), Length of overland Flow (Lg).

Stream Ordering (U)

Stream ordering refers to the hierarchical position of a stream within a basin. Horton[3] evolved a model of stream ordering and suggested that the number of channels of each order of a given basin forms an inverse geometric series with the order. Streams of all orders have been computed and the details at the level of 11fifth order sub watersheds are provided in Table 1. Number of streams in each order varied because of the physiographic conditions of the particular area. Less number of streams in a basin indicates mature topography whereas presence of large number of stream indicates that the topography is youthful and still undergoing erosion[11]. Number of streams has been plotted against stream order and the results have been presented in the Fig. 3. Straight line plots indicate that streams of all three orders considered here (7th, 6th & 5th) adhere to the Horton's principle. In case of Ws_3, Ws_7 and Ws_8 plots of 3rd order stream shows minor variations. Result indicates a common trend that the number of streams decreases with increasing order as evident from a negative exponential function. Points are generally close to

Table1—Linear aspects of Kabani river basin

Basic parameters	Ws1	Ws2	Ws3	Ws4	Ws5	Ws6	Ws7	Ws8	Ws9	Ws10	Ws11	K1	K2	K3	K4	KB
N1	154	264	182	249	224	403	812	163	41	306	233	626	996	1293	674	4229
N2	35	66	40	68	66	89	213	38	11	66	57	130	283	336	145	1118
N3	9	14	12	18	13	24	55	7	4	12	12	28	60	63	36	224
N4	3	4	2	4	3	6	9	3	2	4	3	7	13	15	8	52
N5	1	1	1	1	1	1	1	1	1	1	1	2	3	2	2	11
N6	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1	4
N7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
L1	89.08	153.92	103.31	121.5	113.13	211.21	387.12	71.21	16.78	137.3	119	300.96	507.8	631.5	309	2133.47
L2	38.22	45.96	32.3	46.49	38.72	76.84	152.09	22.89	5.58	46.23	47.8	112.67	190.8	249.5	122	829.75
L3	14.64	16.5	13	23.22	30.18	62.67	77.12	20.05	3.99	24.16	31.9	39.82	97.95	145.4	71.5	441.99
L4	15.88	7.28	10.93	10.85	9.01	13.64	60.12	9.45	3.49	16.42	10.9	31.69	47.08	73.99	49.2	241.68
L5	3.85	15.65	7.4	14.5	9.9	22.37	55.2	5.27	1.59	22.18	14.9	19.4	27.96	61.39	6.86	154.73
L6	-	-	-	-	-	-	-	-	-	-	-	7.2	32.09	7.59	31.2	81.37
L7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	28.37
Rb1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rb2	4.4	4	4.55	3.66	3.39	4.53	3.81	4.29	3.72	4.63	4.09	4.81	3.51	3.84	4.65	3.78
Rb3	3.88	4.71	3.33	3.77	5.08	3.71	4.95	5.43	2.75	5.5	4.75	4.64	4.72	5.33	4.03	4.99
Rb4	3	3.5	6	4.5	4.33	4	4.77	2.33	2	3	4	4	4.61	4.2	4.5	4.31
Rb5	3	4	3	4	3	6	9	3	2	4	3	3.5	4.33	7.5	4	4.73
Rb6	-	-	-	-	-	-	-	-	-	-	-	2	3	2	2	2.75
Rb7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4

straight line in this graph. Correlation coefficients between the number of stream segments and order ranges between 0.98 to 0.99 among the 6th order basin, and between 0.97 to 0.99 among the 5th order basin and for the 7th order it is 0.99.

Bifurcation Ratio (R_b)

Bifurcation ratio characteristically ranges between 3.0 and 5.0 for watershed in which the geologic structures do not distort the drainage pattern[5]. Bifurcation ratio of the Kabani river basin is 4.09 and for the sub basins it varies from 2.61 to 5.6 (Table 1). Bifurcation ratio of the Ws_9 is 2.6. Numbers of stream are less in this basin. The Ws_7 shows high bifurcation ratio (5.6). Elongated shape of the basin also results in the high bifurcation ratio. In general bifurcation ratio of a basin is decreasing with increasing order. Only Ws_9 and Ws_1 are following this common trend.

Stream Length (Lu)

Generally, stream length of a given order is inversely related to stream order. Total stream length decreases from the lower order to successive higher order. Some of the sub basins of Kabani (Ws_2, Ws_4, Ws_5, Ws_6, Ws_{10}, Ws_{11}, Ws_{13}) register variations to this law (Table 1). This change may indicate the lithological differences and varied

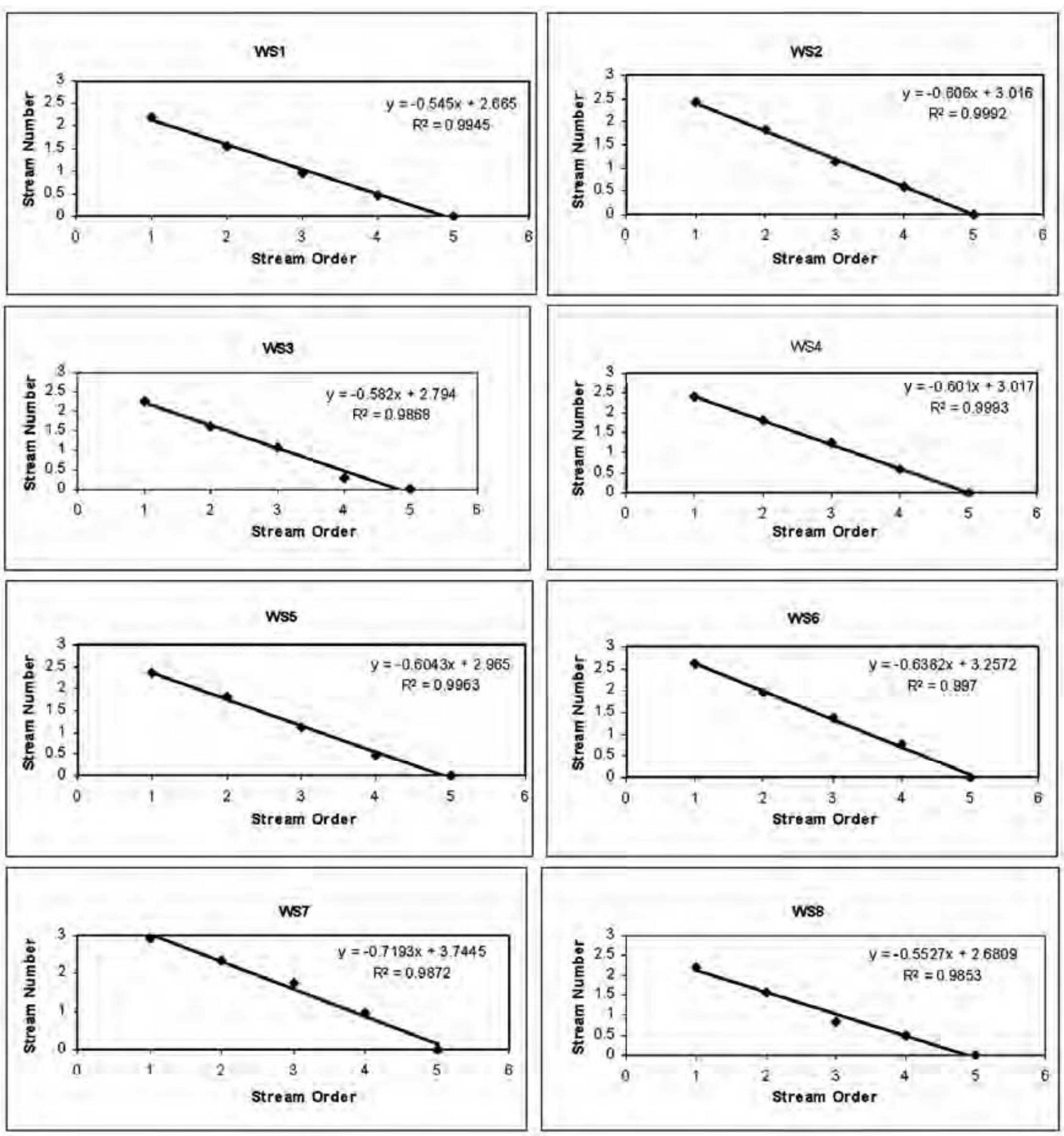

Fig. 3a—Relation between stream order and stream number (*Contd.*)

(*Contd.*)

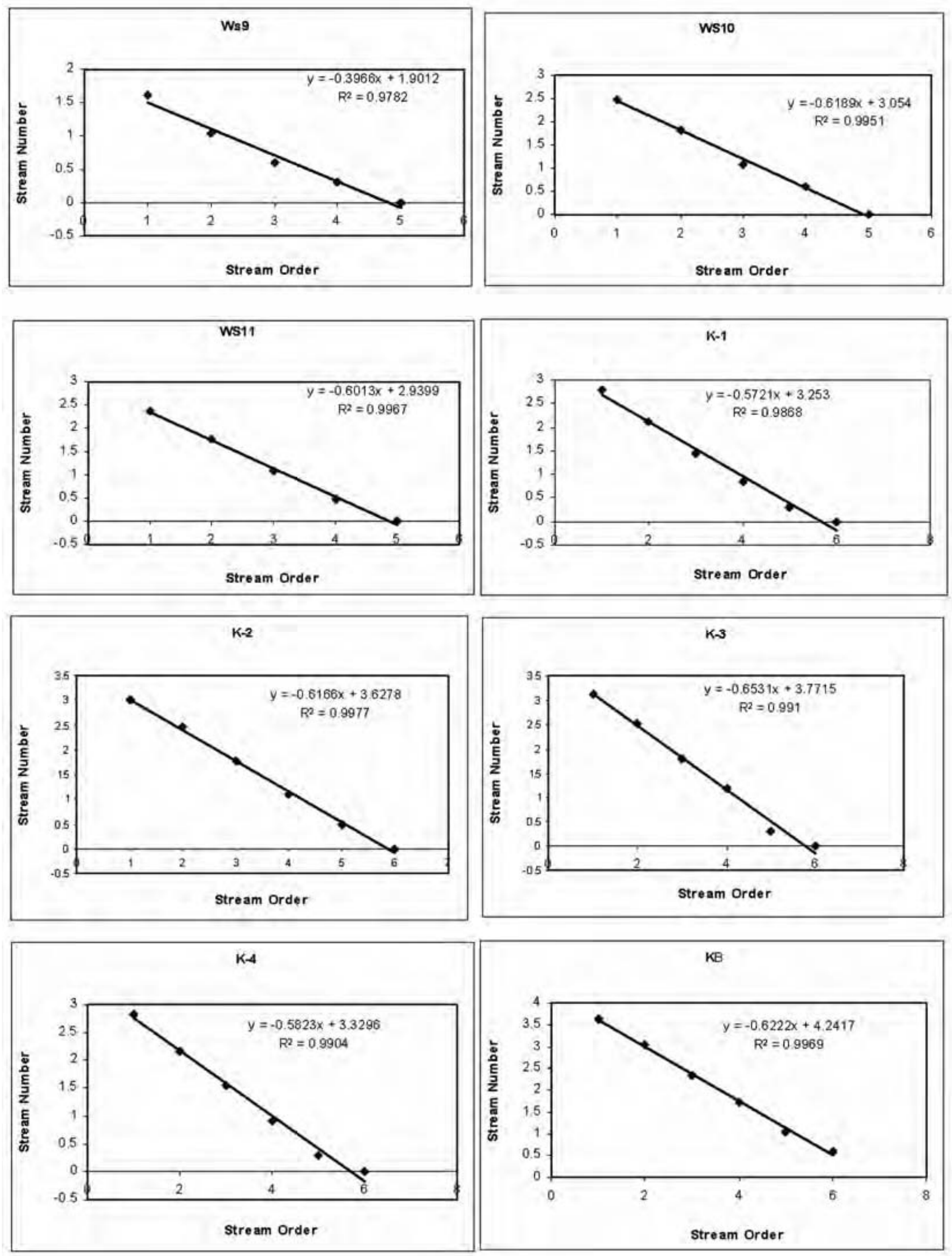

Fig. 3b—Relation between stream order and stream number

pattern at slope of the area. Graph of total stream length against order (Fig. 3) shows negative exponential function, where the total stream length decreases with an increase in order. Regression coefficient ranges from -0.74 to -0.95 and are significant to 1% probability level which shows a strong correlation among variables. When the mean stream length is plotted against order (Fig. 4) it shows a positive exponential function and coefficient of correlation ranges from 0.80 to 0.95.

Length of overland flow (Lg)

Length of overland flow is one of the most important independent variables affecting both the hydrologic and physiographic development of drainage basin[8]. It is the length of water over the ground before it gets concentrated into definite stream channel. It is approximately equal to one half the reciprocal of the drainage density. In this study length of overland flow varies from 0.14 in Ws_1 to 0.25 in the Ws_{11} (Table 2).

Areal Aspects

Areal aspects of drainage basin include measurement of areal elements like basin shape, drainage density (D_d), constant of channel maintenance, form factor (Ff), circularity ratio (R_c) and elongation ratio (R_e), stream frequency (F_s).

Drainage Density (D_d)

Drainage density is one of the most important variables in morphometric analysis because it may be correlated with the dynamic nature of the drainage network and the area of the basin. Drainage density of the Kabani basin is 2.39 km/km^2 and for all the 5[th] order sub basins it ranges from 2.03 km/km^2 in Ws_{11} to 3.43 km/km^2 in Ws_2 (Table 2). Drainage density is low in resistant rock and under high

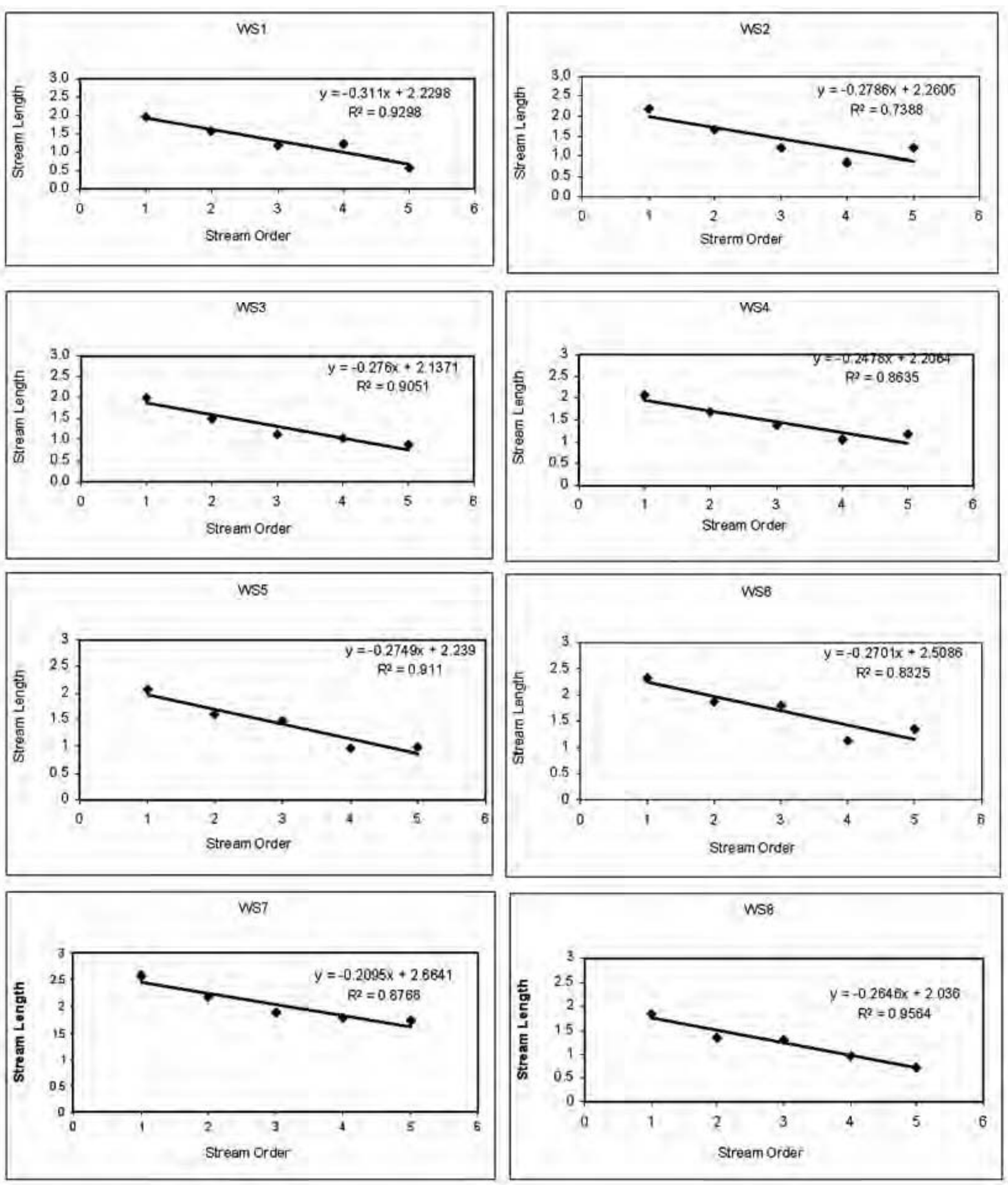

Fig. 4a—Relation between Stream order and stream length (*Contd.*)

(*Contd.*)

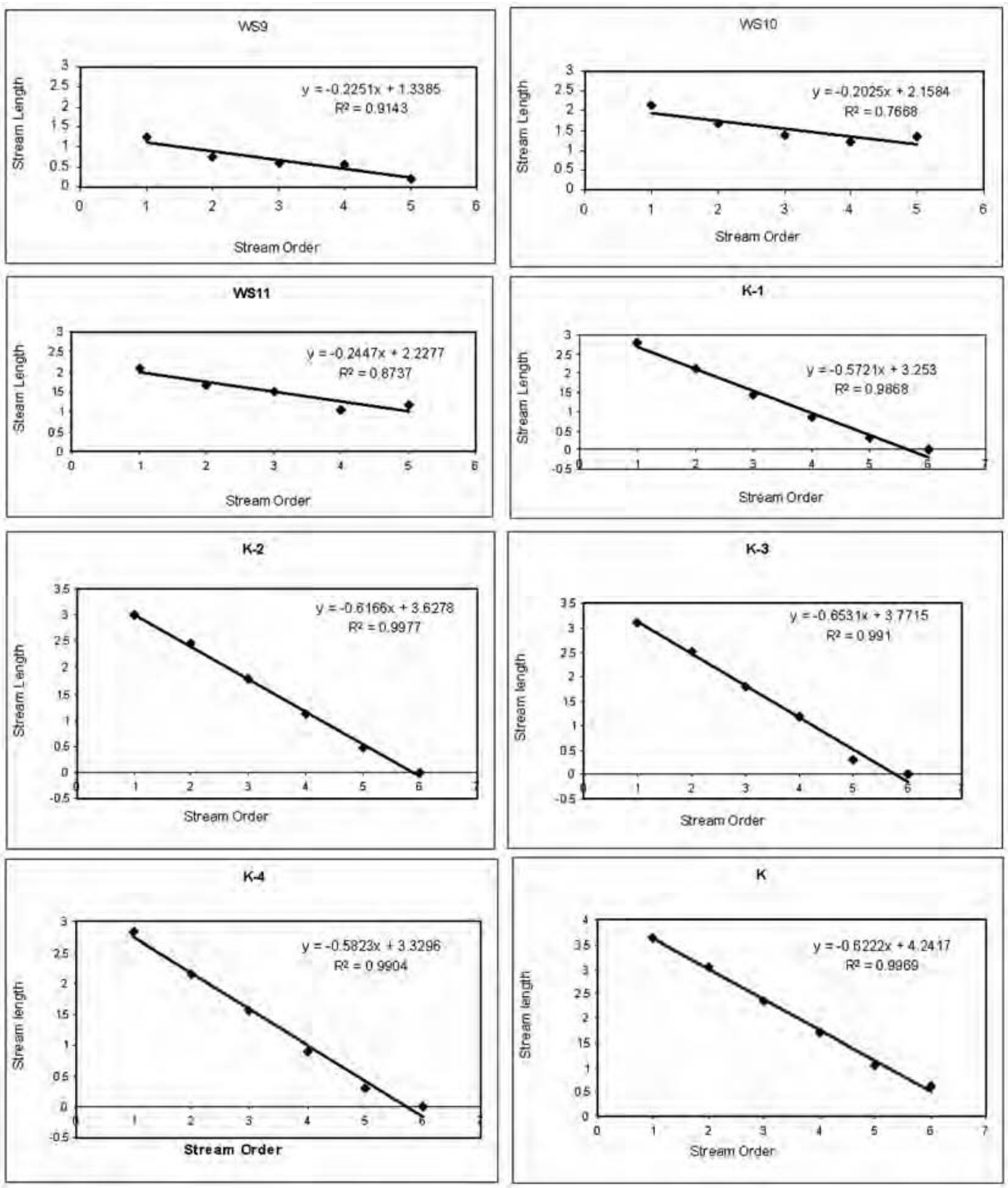

Fig. 4b—Relation between Stream order and stream length

permeable soil. Low drainage density also indicates permeable subsurface strata and is a characteristic feature of course textural drainage (Fig. 5).

Stream Frequency (F_s)

Stream frequency indicates the number of stream segments per unit area[8], which along with drainage density gives the character of underlying lithology in a particular area. It has a positive relation with drainage density, indicating the increase in stream frequency with respect to increase in drainage density. Stream frequency has the highest value in basin Ws_2 (4.99) and the basin Ws_1 shows the minimum value of 2.68 (Table 2).

Basin Shape

Basin shape shows the geometry of the basin. The ideal shape of the basin is frequently disturbed by geological, lithological and relief factors[1]. Three indices namely form factor, elongation ratio have been computed to understand the basin shape. Brief description of each of these items is provided here.

Table 2—Morphometric indices for Kabani river basin

Sub Basins	Area in Km^2	Drainage Density Km/Km^2	Stream Frequency Km^2	Circularity ratio	Form factor	Elongation Ratio	Drainage Texture	Length of Overland flow	Constant of Channel maintence
WS1	75.41	2.14	2.68	0.43	0.61	0.43	5.73	0.23	WS1
WS2	69.57	3.43	4.99	0.4	0.21	0.26	17.11	0.14	WS2
WS3	54.46	3.06	4.35	0.54	0.32	0.31	13.31	0.16	WS3
WS4	74.93	2.89	4.54	0.39	0.49	0.35	12.57	0.17	WS4
WS5	80.56	2.49	3.81	0.72	0.59	0.48	9.49	0.2	WS5
WS6	152.41	2.69	6.49	0.53	0.4	0.41	17.46	0.19	WS6
WS7	272.41	2.68	3.95	0.45	0.56	0.38	10.59	0.19	WS7
WS8	48.43	2.66	4.38	0.65	0.44	0.46	11.65	0.19	WS8
WS9	12.18	2.58	4.84	0.41	0.55	0.36	12.49	0.19	WS9
WS10	102.39	2.41	3.78	0.19	0.38	0.23	9.11	0.21	WS10
WS11	110.41	2.03	2.77	0.45	0.64	0.38	5.62	0.25	WS11
K1	191.45	2.61	4.15	0.43	0.36	0.34	11.08	0.19	K1
K2	191.45	2.67	4.15	0.43	0.36	0.34	11.08	0.19	K2
K3	460.97	2.54	3.71	0.55	0.65	0.45	9.42	0.2	K3
K4	261.06	2.26	3.32	0.46	0.38	0.35	7.5	0.22	K4
KB	1646.65	2.38	3.42	0.38	1.1	0.59	8.14	0.21	KB

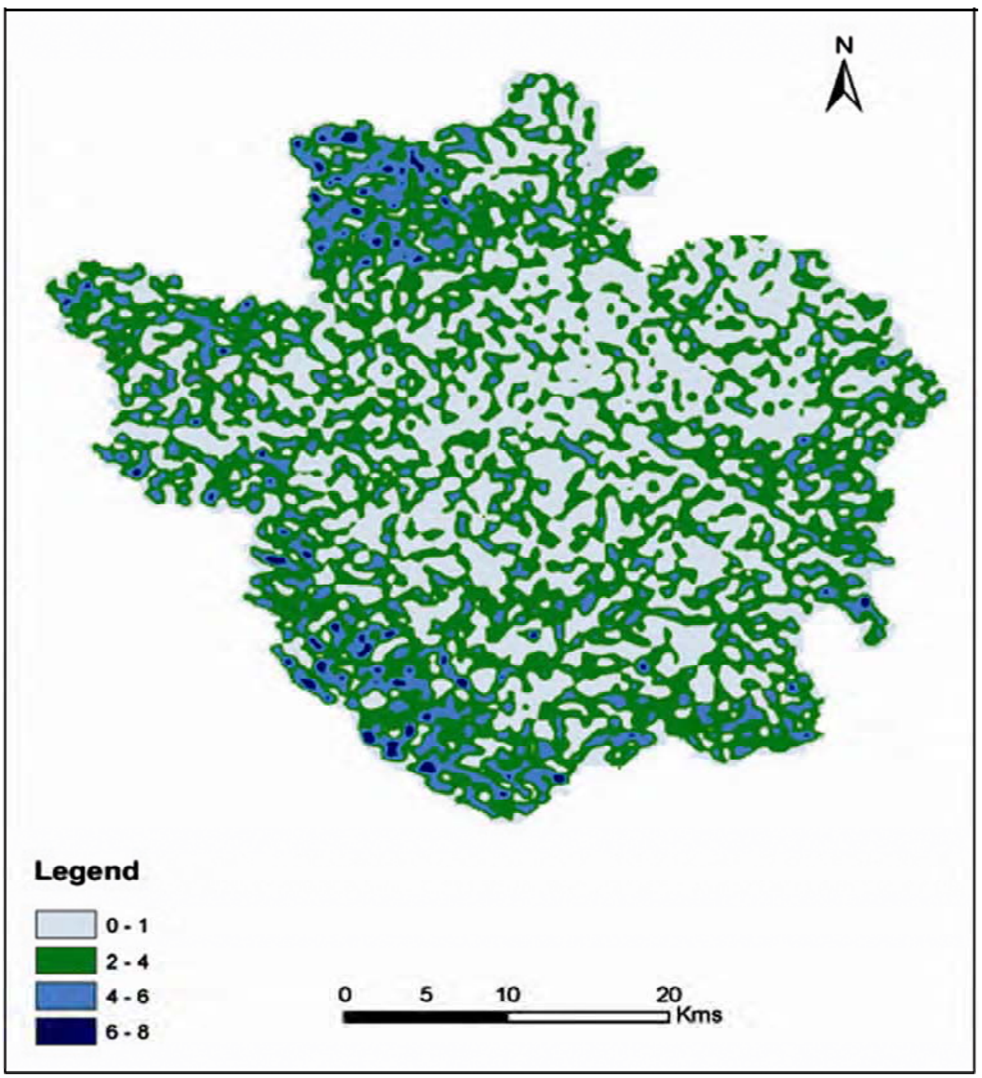

Fig. 5—Drainage density map

Form Factor (F_f)

The fifth order sub basins of Ws_1 (0.61), Ws_5 (0.59), Ws_7 (0.56), Ws_9 (0.55), Ws_{11} (0.64) and sixth order K3 (0.65) have circular shape as evident from Ff value at above 50%. The entire Kabani basin (KB-1.1) also shows the circular shape. The fifth order basins of Ws_2 (0.21), Ws_3 (0.32), Ws_{10} (0.38), and K_1 (0.36), K_2 (0.36), K_4 (0.38) basins have nearly elongated shapes because F_f value of each sub watershed is below 40%. For the remaining basins (Ws_4 ,Ws_6, Ws_8) F_f value varies between 40 to 50% which indicate semi indented shape (Table 2).

Elongation Ratio (R_e)

The value of elongation ratio (R_e) approaches to 1 as the shape of the basin approaches to circle. Value of Re generally varies from 0.6 to 1 over a wide variety of climatic and geological types. Values close to 1 are typical of very low relief, where as values in the range from 0.6 to 0.8 are usually associated with high relief and steep ground slope[6]. Elongation ratio of the entire basin KB indicates 0.59, which is neither very circular nor elongated. Four fifth order sub water sheds namely Ws_1, Ws_5, Ws6, and Ws_8, and two sixth order sub watersheds K_2 and K_3 recorded R_e value below 50% .Where as five sub basins of Ws_3, Ws_4, Ws_7, Ws_9 and Ws_{11} and sixth order sub basins like K_1, and K_4 fall in the category of below 40% and only one sub basin Ws_{10} shows a value below 30%. It may be noted that each eleven sub watershed recorded elongation ratio below 50 % there by indicating elongated shape of the basin (Table 2).

Circularity Ratio (R_c)

Circularity ratios of these basins range from 0.19 to 0.72. Ws_5 has the highest Rc value of 0.72 indicating near circular shape. On the basis of circularity index (R_c) four fifth order sub basins at Ws_3, Ws_5, Ws_6, and K_3 falls in the category of near circular shape as the R_c values of these basins are above 50%. Where as another four basins namely Ws_4, Ws_{10}, K_2 and K_4 (0.35) have elongated shapes as evident from the R_c value of less than 40%. The remaining four fifth order basins Ws_1, Ws_2, Ws_9 and Ws_{11} and two sixth order basins have K_1 and K_3 have R_c values between 40 to 50% (Table.2).

Constant of channel maintenance

Inverse of drainage density is termed as constant of channel maintenance[9]. It is always expressed in square kilometres. Analysis reveals that the value of the constant of channel maintenance varies between 0.27 and 0.47 in Ws_2 and K_4 respectively (Table.1). It means that to maintain one kilometre length of channel in Ws_2 and K_4 watershed area required is 0.27 and 0.47 square kilometre respectively. Lower value indicates that the channel capacity may not be enough to carry higher discharge resulting from the bigger drainage area.

Drainage Texture

Drainage texture (T) depends upon a number of natural factors such as climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief and stage of drainage development. The drainage texture of the all sub basins are shown in Table 1. The T value of the WS_1, Ws_5, Ws_{10}, Ws_{11}, K_2, K_3 and K_4 are of intermediate texture as the values fall between 4.0 to 10.0. The Ws_3, Ws_4, Ws_7, Ws_8, Ws_9 and K_1 have shown fine texture and Ws_2 and Ws_6 are of ultra fine category.

Asymmetry factor

Where the stream network form in the presence of active tectonic deformation, stream pattern can reflect that deformation. One of the simple forms of deformation is tilting, which can be caused by flexure or warping of an area of the earth's surface. Tilting can cause a stream network to become asymmetrical, with more area on one side of the drainage basin than on the other. Asymmetry factor (AF) is a morphometric indices for measuring the degree of asymmetry in a drainage basin[10]. For this study, asymmetry factor for all sub basins are calculated (Table 5). Sub basin of Ws_1, Ws_3, Ws_6, Ws_8, K_1, K_2, and K_3 shows AF value above 50%. In these basins right facing down stream side of the main stream are long compared to tributaries of the left flowing down stream. All other fifth order basins Ws_2, Ws_4, Ws_5, Ws_7, Ws_9, WS_{10}, Ws_{11} and sixth order basins K_4 and the whole Kabani basin (KB) recorded AF value below 50%. If the tilting were in the opposite direction, then the larger stream would be on the left side of the main stream. AF value above or below 50 of a particular watershed may suggest tilt.

Sinuosity index

Sinuosity of a stream is the deviation of its actual path from expected theoretic straight path. It helps for studying the effect of terrain characteristics on the river course. Simultaneously, the degree of sinuosity may give a vivid picture of the stage of basin development as well as landform evolution. The degree of meandering increases the stream length and causes reduction of its gradient. The sinuosity index of the Kabani river basin is generally low (1.03-1.4) in upstream but it increases in the downstream from 1.1 to 2.24 (Table 3).

Relief Measures

Relief measures indicate the potential energy of a drainage system present by virtue of elevation above a given datum.

Table 3—Sinuosity index of major fifth order segments

Watersheds	Divisions	Sinuosity
Ws_1	A	1.63
	B	1.21
	C	1.23
	D	1.15
Ws_2	A	1.02
	B	1.77
	C	1.23
	D	1.09
	E	1.20
	F	1.2
Ws_3	A	1.49
	B	1.03
	C	1.27
	D	1.09
Ws_4	A	1.14
	B	1.09
	C	1.3
	D	1.73
Ws_5	A	1.46
	B	1.04
	C	1.28
	D	1.25
	E	1.71
	F	1.03
Ws_6	A	1.63
	B	1.3
	C	1.02
	D	1.08
Ws_7	A	2.24
	B	1.7
	C	1.82
	D	1.72
	E	1.43
Ws_8	A	1.17
	B	1.27
	C	1.22
	D	1.07
Ws_9	A	1.3
	B	1.13
	C	1.24
Ws_{10}	A	1.83
	B	1.35
	C	1.62
	D	1.12
	E	1.31
	G	1.09
Ws_{11}	A	1.17
	B	1.27
	C	1.27
	D	1.11

Table 4—Relief Aspects of Kabani River Basin

Water shed	Lowest value (m)	Highest value (m)	Relative Relief	Longest Axis (Km)	Relief Ratio
Ws_1	720	1538	818	11.14	0.07
Ws_2	720	1598	898	18.01	0.05
Ws_3	720	1367	647	13.03	0.05
Ws_4	720	1157	437	13.80	0.03
Ws_5	740	1801	1061	10.57	0.10
Ws_6	720	2059	1339	16.89	0.08
Ws_7	720	1906	1186	24.46	0.05
Ws_8	760	923	163	8.6	0.02
Ws_9	760	968	208	5.45	0.04
Ws_{10}	716	1045	329	22.9	0.01
Ws_{11}	698	1100	402	15.65	0.02
K1	720	1598	878	23.01	0.04
K2	720	1801	1081	23.98	0.04
K3	720	2052	1332	26.6	0.05
K4	720	968	248	26.2	0.009
KB	720	2059	1339	38.49	0.03

Relief ratio

Schumm[4] has defined relief ratio as the ratio between the total relief of a basin and longest dimension of the basin parallel to principle drainage line. Relief ratio measures the overall steepness of a drainage basin. Relief ratio in the watershed is varying between 0.01 in Ws_5 to 0.5 in K_3 (Table. 4). It is noticed that high value of relief ratio is associated with steep slope and high relief.

Relative relief

The relative relief represents actual variation of altitude in a unit area with respect to its local base level. Relative relief is an indicator of the general steepness of a basin from summit to mouth. It is more expressive and also useful in understanding morphogenesis. Analysis reveals that the value ranges from 163 in Ws_6 and 1339 in the Ws_8. Relative relief value of the entire basin (KB) is 1339 (Table 5).

Watershed Prioritization

Morphometric analysis is an effective tool for prioritisation of sub-watershed. Soil erosion of a drainage basin is directly linked with the drainage pattern. Linear parameters like bifurcation ratio, Length of overland flow etc. have a direct correlation with run-off and erodibility. Higher the value more is the erodibility. Highest value of the linear parameters was rated as rank 1. In this case shape parameters show an inverse relation with runoff and erodibility. Compound parameters values are calculated and the sub- watershed with the lowest rank was given higher priority. In this study Ws_{10} has the lowest compound parameter value and therefore it needed the higher priority Table 6 & Fig. 6.

Table 5—Asymmetric factor for Kabani river basin

Watershed	Asymmetric factor	Watershed	Asymmetric factor
Ws_1	55.80	Ws_9	22.41
Ws_2	43.71	Ws_{10}	23.64
Ws_3	65.31	Ws_{11}	46.57
Ws_4	45.33	K1	63.3
Ws_5	48.16	K2	69.58
Ws_6	68.08	K3	59.91
Ws_7	44.11	K4	36.39
Ws_8	52.77	KB	47.70

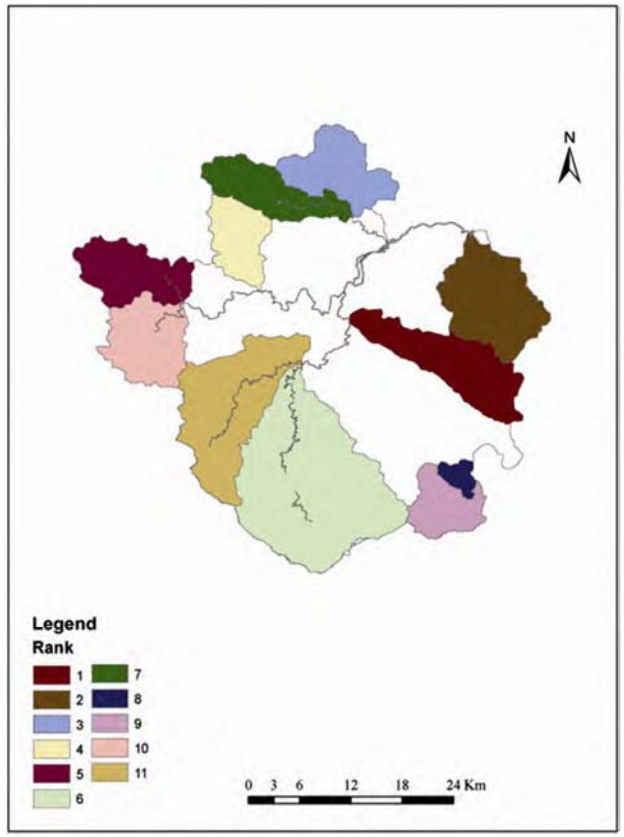

Fig. 6—Watershed prioritisation map

Table 6—Prioritisation of sub watershed using morphometric parameters

Sub watershed	Rb	Dd	Fs	T	Ff	Rc	Re	Rr	Compound parameters	Final priority
Ws_1	9	2	1	2	10	5	8	7	5.5	3
Ws_2	4	11	10	10	1	3	2	8	6.12	7
Ws_3	3	10	6	9	2	8	3	6	5.87	4
Ws_4	5	9	8	8	6	2	4	5	5.88	5
Ws_5	7	4	4	4	9	10	10	9	7.12	10
Ws_6	2	8	11	11	4	7	7	11	7.62	11
Ws_7	1	7	5	5	8	6	6	10	6	6
Ws_8	8	6	7	6	5	9	9	1	6.38	9
Ws_9	10	5	9	7	7	4	5	2	6.13	8
Ws_{10}	3	3	3	3	3	1	1	3	2.5	1
Ws_{11}	6	1	2	1	11	6	6	4	4.63	2

Conclusion

Drainage basin morphometry is the most important approach in understanding the existing geomorphic processes operating within the frame work of a drainage basin. It gives quantitative information on landform. Kabani is a seventh order basin. The 15 morphometric indices are analysed for this study. In drainage network analysis a definite correlation exists between stream order, stream number and stream length. Variation in values of bifurcation ratio reflects the differences in the topographic alignment and geological structure of the basin. Average drainage density of the basin is low. The elongation ratio of all basins indicates the elongated shape of the basin. Assymmetry factor shows the tilting of the basin. Sub basins of Kabani river basin shows the fact that the drainage patterns are largely controlled by geological structure, lithological characteristics, and general relief etc. Morphometric data generated through this study were used to prioritise the water shed. In this analysis the Ws_{10} shows lowest rank thus it was accorded higher priority.

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