



Drainage basin analysis for characterization of 3rd order watersheds using Geographic Information System (GIS) and ASTER data

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Abstract: An attempt has been made to study and characterize the drainage morphometry and its influence on hydrology of Nalluru Amani Kere Watershed (NAKW), Karnataka, India. Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data were used for preparing Digital Elevation Model (DEM) and slope maps. Geographical information system (GIS) was used in evaluation of linear, areal and relief aspects of morphometric parameters. NAKW is a constituent of the Cauvery river basin, in Karnataka state and covers an area of 415.68 km², representing arid climate. The lower order streams are mostly dominating the basin. The mean R_b of the 3rd order watersheds (MWS) is 3.38 which indicates that the drainage pattern is influenced marginally by geological structures. Length of overland flow indicates that in majority of MWS have short flow- paths, with steep ground slopes, reflecting the areas associated with more run-off and less infiltration. The remaining MWS indicate moderate ground slopes, where the run-off and infiltration are moderate and long flow-paths and gentle ground slopes, which reflects areas of less surface run-offs and more infiltration. Bifurcation ratio indicates absence of any significant structural control on the development of the drainage. Relief ratio indicates that the discharge capabilities of some of the MWS are low to moderate and the groundwater potential is moderate to good. These studies are very useful for planning in construction of rainwater harvesting structures and watershed management.

Keywords: Morphometry, ASTER, Drainage, Bifurcation ratio, infiltration ratio

1. Introduction

The drainage basin analysis is important in many hydrological investigations like assessment of groundwater potential, groundwater management and environmental assessment. Hvdrologists and geomorphologists have recognized that certain morphometric relations are very important in determining the runoff characteristics, geographic and geomorphic characteristics of drainage basin systems. Various important hydrological phenomena can be correlated with the physiographic characteristics of drainage basins such as size, shape, slope of drainage area, drainage density, size and length of the contributories (Rastogi and Sharma, 1976). Watershed management involves proper utilization of land, water, forest and soil resources of a watershed for optimum production with minimum hazard to natural resources (Biswas et al., 1999). Drainage analysis based on morphometric parameters is very important for watershed planning since it gives an idea about the watershed characteristics in terms of slope, topography, soil condition, runoff characteristics, surface water potential etc. The development of landforms and drainage network depends on the bed rock lithology and associated geological structures. Hence, information on geomorphology, hydrology, geology and land cover can be obtained by studying reliable information of the drainage pattern and texture (Astras and Soulankellis, 1992). Thus the role of lithology and geologic structures in the development of stream networks can be better understood by studying the nature and type of drainage pattern and by a quantitative morphometric analysis (Nag and Chakraborti, 2003).

2. Study area

The present work is of Nallur Amanikere watershed (NAKW), located N–E of Gundlupet town, near Ingalavadi village, Chamrajnagar district, Karnataka, India (Fig. 1). The study area geographically lies between $76^{\circ} 30'$ E and $76^{\circ} 50'$ E longitude and $11^{\circ} 38'$ N and $11^{\circ} 52'$ N latitude, covers an area of 415.68 km².



Figure 1: Location map of study area

3. Method adopted

The base maps of the NAKW were prepared using Survey of India (SOI) Topographic maps on a 1:50,000 scale. The 30m resolution Digital Elevation Model

(DEM) data was downloaded from the website http://www.jspacesystems.or.jp/ersdac/GDEM/E/4.htm 1.Based on these data, the slope, aspect and topographic elevation maps for the watersheds were prepared. The drainage network of the watersheds were scanned from SOI Toposheets no. 58A/9, 58A/10, 58A/13 and 58A/14 (1:50,000) and digitized in ArcGIS 9.2 platform. The channels were classified according to drainage order following Strahler (1964). Watershed parameters, such as area, perimeter, length, stream length and stream order were also calculated. Later, these parameters were used to determine other influencing factors, such as bifurcation ratio, stream length ratio, stream frequency, drainage density, texture ratio, total relief, relief ratio, elongation ratio, circulatory ratio, form factor and length of overland flow.

4. Drainage pattern analysis

The drainage pattern is the planimetric arrangement of stream engraved into the land surface by a drainage system. The aggregates of drainage establish a design on the earth's surface, adjusted to topographic, structural and lithological controls. The drainage pattern is an indicator of landforms and bedrock type. It also suggests soil characteristics and site drainage condition. The drainage pattern may reflect original slope, original structure or the modification of the earth surface, including uplift depression, tilting and other structural elements like faulting, folding, warping and jointing. The drainage pattern may be trellised, rectangular, parallel, dendritic or radial. In the study area all MWS belongs to dendritic type of drainage pattern (Fig. 2 and 3).



Figure 2: Drainage map of Nalluru Amani Kere watershed



Figure 3: 3rd order watersheds of Nalluru Amani Kere watershed

5. Quantitative morphometric analysis

Morphometric analysis provides a quantitative description of the basin geometry to understand initial slopes or inequalities in the rock hardness, structural controls, recent diastrophism, geological and geomorphic history of the drainage basin (Strahler, 1964). Morphometric analysis requires measurements of linear features, the gradients of the channel network and contributing ground slopes of the drainage basin (Nantiyal, 1994). One of the advantages of quantitative analysis is that many of the basin parameters derived are in the form of ratios or dimensionless numbers, thus providing an effective comparison irrespective of the scale (Krishnamurthy et al., 1996).

5.1 Linear aspects: In the present study linear aspects include stream order, stream length, stream length ratio, length of overland flow, bifurcation ratio, RHO coefficient (RHO) are calculated using formulae suggested by various authors (Table 1) and studied.

5.1.1 Stream order (U) and Stream number (N): The stream order is a measure of degree of stream branching within a watershed. In the study area the highest order obtained is 6th order and hence designated as 6th order watershed. Each segment of the stream was numbered starting from the first order to the maximum order present in each of the sub-basins. After numbering, the drainage-network elements are assigned their order numbers, the segments of each order are counted to yield the number Nu of segments of the given order u.

5.1.2 Stream length (Lu): Length of the stream is an indicator of the area contribution to the watershed, steepness of the drainage watershed as well as the degree of drainage. Steep and well drained areas generally have numerous small tributaries; whereas, in plains, where soils are deep and permeable, only relatively long tributaries (generally perennial streams) will be in existence. Thus, this factor gives an idea of the efficiency of the drainage network. Generally the total length of the stream segments decrease with stream order. Deviation from its general behavior indicates that the terrain is characterized by high relief and /or moderately steep slopes, underlying by varying lithology and probable uplift across the watershed (Singh and Singh, 1997). For the NAKW stream length of each order is presented in the table 2 and shows that the total stream length (\sum Lu) in the MWS is minimum, 1.24 km in the MWS-12 and maximum 11.70 km in MWS-22. The sum of average stream lengths of first, second and third order streams (Table 2) indicates that the first order streams are longer than the higher order streams. In the average individual stream length, there is increasing trend from first order to third order. However, in some of the MWS the 3rd and 2nd order stream length is smaller than their lower order. In MWS-3, 3^{rd} order is shorter than 2^{nd} order, which is due to the variation in relief over which the segments occur.

5.1.3 Mean stream length (Lsm): Lsm of a channel is a dimensional property and reveals the characteristic size of the drainage network components and its contribution watershed surfaces (Strahler, 1964). Generally it is observed that the mean stream length of any given order is greater than that of the lower order but less than that of the next higher order. For NAKW highest and lowest mean stream length is found to vary between 0.87 and 0.40, 2.48 and 0.16, 10.09 and 0.48 for 1^{st} , 2^{nd} and 3^{rd} order stream respectively. Table 2 shows the stream number and stream length of 1^{st} , 2^{nd} and 3^{rd} order MWS of NAKW. This indicates the structural influence in the formation of streams in few areas.

5.1.4 Stream length ratio (R_L): R_L is the ratio (Table 1) computed for the 31 MWS is presented in Table 2. The mean R_L vary at the basin and sub-watershed levels. The values of the mean R_L vary from 0.36 (MWS-5) to 2.36 (MWS-25) for sub-watersheds. It is noticed that the R_L between successive stream orders of the sub-watershed vary due to differences in slope and topographic conditions. R_L has an important relationship with the surface water discharge and erosional stage of the basin.

5.1.5 Length of over land flow (Lg): Length of overland flow is the flow of water over the surface before it becomes concentrated in definite stream channels. The length of overland flow is a measure of erodibility and is one of the independent variables affecting both the hydrologic and physiographic development of the drainage watershed. Horton (1945) defined the length of overland flow as the length of flow path, projected to a horizontal plane of the rain flow from a point on the drainage divide to a point on the adjacent stream channel. The shorter the length of overland flow, the quicker the surface runoff from the streams (Kumar et al., 2011). Classification of MWS based on Lg is presented in Table 3. Lg values less than 0.20 km km⁻² is found in 13 MWS in the study area. This indicates short flow- paths, with steep ground slopes, reflecting the areas associated with more run-off and less infiltration. The Lg values between 0.2 and 0.3 km km⁻² is observed in 8 subwatersheds, indicating the presence of moderate ground slopes, where the run-off and infiltration are moderate. The Lg value more than 0.3 km km⁻² is observed in ten MWS indicating the occurrence of long flow-paths, and thus, gentle ground slopes, which reflects areas of less surface run-offs and more infiltration.

5.1.6 Bifurcation ratio (R_b): This is the universal value for maturely dissected drainage basins (Rao and Babu, 1995). The number of stream segments of any given order will be fewer than for the next lower order but more numerous than for the next higher order. According to Strahler (1957), in a region of uniform climate and stage of development, the R_b tends to remain constant from one order to next order. The irregularities of the drainage watershed depend upon lithological and geological development, leading to changes in the values from one order to the next. An elongated watershed has higher Rb than the circular watershed. The computed values of Rb of 3rd order MWS in the NAKW vary from 2.00 to 6.00 with an average value of 3.35 for second order streams, 2.00 to 10.00 with an average value of 3.42 for third order streams (Table 2). The average of all the bifurcation ratios in a drainage basin gives the mean bifurcation ratio (R_{bm}). The Rb values less than 5 indicate geomorpholgical control, while R_b values greater than 5 indicate structural control on the development of the drainage pattern. The observed average value of R_b of 3rd order MWS is less than 5 (Table 2), which indicates that the structural control over the development of drainage network is not as pronounced as the geomorphic control. However, the MWS-15 and 16 in the second-order streams, the MWS-7, 16, 18, 22 and 31 in the third-order streams have an R_b greater than 5. This indicates the influence of structural control on the development of the drainage network in these MWS. It is mainly due to the structural disturbances in region. It is also noted that the MWS-2, 9, 13, 17, 19, 24, 25, 26 and 30 in the second-order streams, and the MWS-2, 5, 6, 9, 11, 12, 14, 19, 20, 21, 24, 26, 29 and 30 in the third-order streams have R_b less than 3, which indicate absence of any significant structural control on the development of the drainage. Strahler (1957) demonstrated that bifurcation ratio shows a small range of variation for different regions/environment except where the powerful geological control dominates. If the R_b is not same from one order to its next order, then these irregularities are dependent upon the geological and lithological development of the drainage basin (Strahler, 1964). The mean bifurcation ratio (R_{bm}) for the MWS is presented in Table 2. In the study area R_{bm} varies from 2.00 (MWS-2 and 24) to 6.50 (MWS-18), lower values in MWS-2 and 24 suggest less structural disturbance, whereas higher value in MWS-18 indicates that it has structurally controlled drainage pattern.

	Table 1: F	ormula for computation of morphometric parameters	
S.No	Parameters	Formulae	References
		Linear aspects	
1	Stream Order (U)	The smallest permanent streams are called "first order". Two first order streams join to form a larger, second order stream; and so on	Strahler (1964)
2	Stream Length(Lu)	The average length of streams of each of the different orders in a drainage basin tends closely to approximate a direct geometric ratio.	Horton (1945)
3	Mean Stream Length (Lsm)	Lsm = Lu/Nu,	Strahler (1964)
5	Stream Length Ratio (RL)	$RL = Lu/L_{u-1}$	Horton (1945)
6	Length of overland flow (Lg)	$Lg=1/2D_d$	Horton (1945)
7	Bifurcation Ratio (R _b)	$R_{\rm h} = Nu/N_{\rm u+1}$	Horton (1932)
8	Mean Bifurcation Ratio	R_{hm} = Average of bifurcation	Strahler (1964)
	(R _{hm})	ratio of all Orders	
9	RHO Co-efficient (RHO)	RHO= R_l/R_b : The ratio between the stream length ratio and the Bifurcation ratio	Mesa (2006)
		Areal aspects	
1	Area (A)	Area of the basin in km ²	
2	Perimeter (P)	Perimeter of the basin in km	
3	Form factor (F_f)	$F_f = A/Lu^2$	Horton (1945)
4	Compactness Coefficient	Cc=P/Circumference of the circle	Gravelius (1914)
	(Cc)	of the same area	Hidore (1964)
5	Basin shape (Bs)	$Bs = Lb^2 / A$	Horton (1945)
6	Circularity ratio (Rc)	$Rc=4\pi A/P^2$	Strahler (1964)
7	Elongation ratio (Re)	$Re=D/L=1.128\sqrt{A/L}$	Schumm (1956)
8	Drainage density (D_d)	$D_d = \sum Lu/A$	Horton (1945)
9	Drainage texture (T)	$T = D_d x Fs$	Smith (1950)
10	Texture ratio (Tr)	$Tr = \sum Nu/P$,	Smith (1950)
11	Constant channel maintenance (Cm)	$C=1/D_d$	Schumm (1956)
12	Stream frequency(Fs)	$Fs = \sum Nu/A$,	Horton (1945)
13	Infiltration Number (If)	$If = Fs(D_d)$	Faniran (1968)
14	Lemniscate's (k)	$k = Lb^2 \pi/(4A)$	Chorely et al. (1957)
		Relief aspects	· /
1	Relief (R)	R = H - h	Hadley and Schumm (1961)
2	Relief Ratio (Rf)	Rf = R/L	Schumm (1963)
3	Slope	$Sb = H-h/L^2$	Mesa (2006)
4	Ruggedness number (Rn)	$Rn = D_d (H / 1000)$	Strahler (1964)
5	Melton's Ruggedness	$MRn = H / A^{0.5}$	Melton(1965).

 Table 1: Formula for computation of morphometric parameters

MWS		Ν	I			Lu	km)	2: LII	lear	<u>asp</u> Mean	Lu (k	$\frac{01 \text{ IN}F}{m}$	AIX SU	D-wat RL	ersne	us Lø		R,		R	HO Coe	f
M 0 5.		1				Lu	(KIII)			(I	sm)	,		RE		15		ц		K	110 000	1.
	1	2	3	Total	1	2	3	Total	1	2	3	Total	1-Feb	2-Mar	Mean		R _{b1}	R _{b2}	Mean	RHO1	RHO2	Mean
1	16	5	1	22	10.8	4.09	6.72	21.6	0.7	0.8	6.7	8.21	0.38	1.64	1.01	0.3	3.2	5	4.1	0.12	0.33	0.22
2	4	2	1	7	2.24	1.07	1.95	5.26	0.6	0.5	2	3.05	0.48	1.82	1.15	0.4	2	2	2	0.24	0.91	0.58
3	9	3	1	13	7.83	4.05	3.07	15	0.9	1.4	3.1	5.29	0.52	0.76	0.64	0.3	3	3	3	0.17	0.25	0.21
4	10	3	1	14	6.6	2.44	3.79	12.8	0.7	0.8	3.8	5.26	0.37	1.55	0.96	0.3	3.3	3	3.17	0.11	0.52	0.31
5	9	2	1	12	5.94	2.82	0.68	9.44	0.7	1.4	0.7	2.75	0.47	0.24	0.36	0.3	4.5	2	3.25	0.11	0.12	0.11
6	9	2	1	12	6.38	4.48	0.48	11.3	0.7	2.2	0.5	3.43	0.7	0.11	0.4	0.2	4.5	2	3.25	0.16	0.05	0.1
7	21	6	1	28	12.1	3.43	5.99	21.5	0.6	0.6	6	7.14	0.28	1.75	1.02	0.2	3.5	6	4.75	0.08	0.29	0.19
8	10	3	1	14	4.74	1.86	3.16	9.76	0.5	0.6	3.2	4.25	0.39	1.7	1.05	0.2	3.3	3	3.17	0.12	0.57	0.34
9	5	2	1	8	3.28	1.4	0.69	5.37	0.7	0.7	0.7	2.05	0.43	0.49	0.46	0.1	2.5	2	2.25	0.17	0.25	0.21
10	13	3	1	17	6.22	2.45	2.01	10.7	0.5	0.8	2	3.31	0.39	0.82	0.61	0.2	4.3	3	3.67	0.09	0.27	0.18
11	8	2	1	11	4.45	0.68	0.98	6.11	0.6	0.3	1	1.88	0.15	1.44	0.8	0.1	4	2	3	0.04	0.72	0.38
12	8	2	1	11	3.74	0.32	0.61	4.67	0.5	0.2	0.6	1.24	0.09	1.91	1	0.1	4	2	3	0.02	0.95	0.49
13	8	3	1	12	3.46	1.23	1.82	6.51	0.4	0.4	1.8	2.66	0.36	1.48	0.92	0.2	2.7	3	2.83	0.13	0.49	0.31
14	8	2	1	11	3.25	1.22	0.46	4.93	0.4	0.6	0.5	1.48	0.38	0.38	0.38	0.1	4	2	3	0.09	0.19	0.14
15	24	4	1	29	9.65	4.59	8.42	22.7	0.4	1.2	8.4	9.97	0.48	1.83	1.16	0.3	6	4	5	0.08	0.46	0.27
16	26	7	1	34	13.1	6.95	6.28	26.3	0.5	1	6.3	7.78	0.53	0.9	0.72	0.2	3.7	7	5.36	0.14	0.13	0.14
17	14	5	1	20	8.22	2.82	4.19	15.2	0.6	0.6	4.2	5.34	0.34	1.49	0.91	0.2	2.8	5	3.9	0.12	0.3	0.21
18	30	10	1	41	18.1	6.72	5.96	30.8	0.6	0.7	6	7.24	0.37	0.89	0.63	0.2	3	10	6.5	0.12	0.09	0.11
19	5	2	1	8	3.5	0.74	2.71	6.95	0.7	0.4	2.7	3.78	0.21	3.66	1.94	0.2	2.5	2	2.25	0.08	1.83	0.96
20	6	2	1	9	2.44	1.03	1.59	5.06	0.4	0.5	1.6	2.51	0.42	1.54	0.98	0.2	3	2	2.5	0.14	0.77	0.46
21	5	2	1	8	3.59	0.62	0.63	4.84	0.7	0.3	0.6	1.66	0.17	1.02	0.59	0.2	2.5	2	2.25	0.07	0.51	0.29
22	22	7	1	30	12.8	7.18	10.1	30.1	0.6	1	10	11.7	0.56	1.41	0.98	0.3	3.1	7	5.07	0.18	0.2	0.19
23	10	3	1	14	6.33	1.56	2.26	10.2	0.6	0.5	2.3	3.41	0.25	1.45	0.85	0.5	3.3	3	3.17	0.07	0.48	0.28
24	4	2	1	1.5	1.88	2.27	2.26	6.41	0.5	1.1	2.3	3.87	1.21	1	1.1	0.4	2	2	2	0.6	0.5	0.55
25	10	4	1	15	1.73	6.38	6.57	14.7	0.2	1.6	6.6	8.34	3.69	1.03	2.36	0.4	2.5	4	3.25	1.48	0.26	0.87
26	5	2	1	8	2.99	1.68	0.61	5.28	0.6	0.8	0.6	2.05	0.56	0.36	0.46	0.3	2.5	2	2.25	0.22	0.18	0.2
27	9	3	1	13	4.57	3.28	1.64	9.49	0.5	1.1	1.6	5.24	0.72	0.5	0.61	0.2	3	3	3	0.24	0.17	0.2
28	16	3	1	20	6.19	3.48	3.48	13.2	0.4	1.2	3.5	5.03	0.56	1 10	0.78	0.3	5.5	3	4.17	0.11	0.33	0.22
29	6	2	1	9	5.18	2.05	2.42	9.65	0.9	1	2.4	4.51	0.4	1.18	0.79	0.3	5	2	2.5	0.13	0.59	0.36
30 21	5 25	2	1	ð 22	3.81 21.1	2.23	3.3/ 7.70	11.4	0.8	1.1	5.4 7.9	1.25	0.59	2.41	1.5	0.5	2.5	4	2.23	0.23	0.00	0.72
Augrage	25	0	1	32	21.1	14.9	1.19	43.8	0.9	2.5	1.8	11.1	0.7	0.52	0.01	0.3	4.2	24	2.08	0.17	0.09	0.13
Average	11.6	5.4	1	16	6.65	3.23	3.38	13.3	0.6	0.9	5.4	4.89	0.48	1.05	0.77	0.3	3.4	5.4	3.38	0.14	0.51	0.23

 Table 3: Classification of MWS based on length of overland flow (Lg)

Lg (km km ⁻²)	Class	MWS	% of MWS
<0.2	Low	6,7,9,10, 11,12,13,14,17, 18,19,20,21	42
0.2 to 0.3	Medium	5,8,15, 16,26,27,28,31	25
>0.3	High	1,2,3,4,22,23,24, 25,29,30	33

5.1.7 RHO coefficient (RHO): It is considered to be an important parameter as it determines the relationship between the drainage density and the physiographic development of the basin and allows the evaluation of the storage capacity of the drainage network (Horton 1945). The mean RHO coefficient of the NAMW varies from 0.10 (MWS-6) to 0.96 (MWS-19) while the RHO₁ of the sub-basins varies between 0.02 (MWS-12) to 1.48 (MWS-25) and RHO₂ varies between 0.05 (MWS-6) to 1.83 (MWS-19) (Table 2). MWS with higher values of RHO have higher water storage during flood periods and as such attenuate the erosion effect during elevated discharge (Mesa, 2006).

5.2 Areal/shape factors

Various hydrologic phenomena such as size, shape, slope of drainage area, drainage density, size and length of the contributories can be correlated with the physiographic characteristics of the watershed. Areal aspects of a watershed of given order is defined as the total area projected upon a horizontal plane, contributing overland flow to the channel segment of the given order including all tributaries of lower order. The watershed shape has a significant effect on stream discharge characteristics. For example; an elongated watershed having a high bifurcation ratio can be expected to have alternated flood discharge. But on the other hand, a round or circular watershed with a low bifurcation ratio may have a sharp flood discharge. The shape of a watershed has a profound influence on the runoff and sediment transport process. The shape of the drainage watershed also governs the rate at which water enters the stream. The quantitative expression of

				Tab	ole 4: 4	Areal	aspects	s of N	AK su	b-wat	ershee	ls			
MWS No.	Α	L _b	Р	Bs	Cc	Dd	Τ	Tr	Cm	F _f	Fs	Rc	Re	If	Κ
1	14.3	7.51	18.37	3.94	1.37	1.51	2.32	1.2	0.66	0.25	1.54	0.53	0.11	2.32	3.1
2	3.63	3	8.85	2.48	1.31	1.45	2.78	0.79	0.69	0.4	1.92	0.58	0.06	2.78	2
3	9.11	5.44	13.71	3.25	1.28	1.64	2.34	0.95	0.6	0.3	1.43	0.6	0.09	2.34	2.6
4	8.49	4.67	12.8	2.57	1.23	1.51	2.49	1.09	0.66	0.38	1.65	0.65	0.09	2.49	2
5	4.92	3.81	9.97	2.95	1.26	1.92	4.68	1.2	0.52	0.33	2.44	0.62	0.07	4.68	2.3
6	4.2	3.36	8.76	2.69	1.2	2.7	7.69	1.37	0.37	0.37	2.85	0.68	0.06	7.69	2.1
7	8.12	5.18	15.24	3.3	1.5	2.65	9.13	1.84	0.37	0.3	3.45	0.43	0.09	9.13	2.6
8	4.53	3.41	8.84	2.57	1.17	2.15	6.65	1.58	0.46	0.38	3.09	0.72	0.06	6.65	2
9	1.07	2.2	5.06	4.52	1.37	5.02	37.5	1.58	0.19	0.22	7.46	0.52	0.03	37.5	3.6
10	3.18	2.69	7.58	2.28	1.2	3.36	18	2.24	0.29	0.43	5.35	0.69	0.05	18	1.8
11	1.71	2.05	5.59	2.46	1.2	3.55	22.7	1.97	0.28	0.4	6.4	0.69	0.04	22.7	1.9
12	1.15	1.6	4.38	2.23	1.14	4.05	38.5	2.51	0.24	0.44	9.51	0.75	0.03	38.5	1.8
13	2.53	2.84	7.38	3.19	1.3	2.57	12.2	1.63	0.38	0.31	4.73	0.58	0.05	12.2	2.5
14	1.18	2.03	4.92	3.49	1.27	4.16	38.5	2.24	0.24	0.28	9.27	0.61	0.03	38.5	2.7
15	13	8.72	21.15	5.83	1.65	1.74	3.86	1.37	0.57	0.17	2.22	0.36	0.11	3.86	4.6
16	10.9	6	16.39	3.32	1.4	2.42	7.58	2.07	0.41	0.3	3.13	0.5	0.1	7.58	2.6
17	5.04	4.34	10.65	3.74	1.33	3.02	11.9	1.88	0.33	0.26	3.96	0.55	0.07	11.9	2.9
18	10.8	5.88	16.1	3.2	1.38	2.85	10.8	2.55	0.35	0.31	3.8	0.52	0.1	10.8	2.5
19	2.48	3.87	8.9	6.04	1.59	2.8	9.02	0.9	0.35	0.16	3.22	0.39	0.04	9.02	4.7
20	1.78	2.6	6.13	3.8	1.29	2.85	14.4	1.47	0.35	0.26	5.05	0.59	0.04	14.4	3
21	1.81	2.17	5.78	2.6	1.21	2.68	11.8	1.38	0.37	0.38	4.41	0.68	0.04	11.8	2
22	19.9	9.2	28.19	4.26	1.78	1.51	2.28	1.06	0.66	0.23	1.51	0.31	0.14	2.28	3.3
23	10.9	6.1	15.99	3.41	1.36	0.93	1.19	0.88	1.07	0.29	1.28	0.53	0.1	1.19	2.7
24	5.37	3.65	10.04	2.48	1.22	1.19	1.55	0.7	0.83	0.4	1.3	0.66	0.07	1.55	2
25	18.5	7.24	19.15	2.83	1.25	1.28	1.03	0.78	0.78	0.35	0.81	0.63	0.13	1.03	2.2
26	2.59	2.37	6.15	2.17	1.07	2.03	6.27	1.3	0.49	0.46	3.08	0.86	0.05	6.27	1.7
27	3.95	3.46	8.77	3.03	1.24	2.4	7.88	1.48	0.41	0.32	3.29	0.64	0.06	7.88	2.4
28	6.88	5.05	12.15	3.71	1.3	1.91	5.55	1.65	0.52	0.26	2.91	0.58	0.08	5.55	2.9
29	6.13	4.86	11.12	3.85	1.26	1.57	2.31	0.81	0.63	0.25	1.47	0.62	0.07	2.31	3
30	11.9	7.16	17.59	4.3	1.43	0.96	0.64	0.45	1.03	0.23	0.67	0.48	0.1	0.64	3.4
31	25.8	9.95	24.21	3.84	1.34	1.7	2.1	1.32	0.58	0.26	1.24	0.55	0.16	2.1	3
Average	7.29	4.59	11.93	3.36	1.32	2.32	9.86	1.43	0.51	0.31	3.37	0.58	0.07	7.83	2.6

where A=Area of Watershed (km²), L_b = Watershed Length (km), P=Perimeter (km), Bs=Shape factor, C_c = Compactness Constant, D_d =Drainage density (km/km²), T=drainage texture (km/km²), Tr=Texture ratio,

watershed can be characterized by form factor, compaction coefficient, circularity ratio, drainage density and elongation ratio which is discussed in the present study.

5.2.1 Form factor (F_f): The value of form factor would always be greater than 0.78 for a near perfect circular watershed. Smaller the value of the form factor, more elongated will be the watershed. Form factor of NAKW varies from 0.17 (MWS-15) to 0.46 (MWS-26) for 3^{rd} order basins (Table 4).

5.2.2 Compactness coefficient (C_c): Compactness coefficient (C_c) is, also known as Gravelius Index (GI), used to express the relationship of a hydrologic basin to that of a circular basin having the same area as

the hydrologic basin. A circular basin is the most susceptible from drainage point of view because it will yield shortest time of concentration before peak flow occurs in the basin (Nookaratnam et al., 2005). Cc is indirectly related with the elongation of the basin area. Lower values of this parameter indicate the more elongation of the basin and less erosion and vice-versa. Compactness coefficient of NAKW 3rd subwatershed is found to be vary between 1.07 (MWS-27) to 1.78 (MWS-22) (Table 4).

5.2.3 Shape factor (Bs): Shape factor of NAKW 3^{rd} order SWS is found to be varying between 2.17 (MWS-26) to 6.09 (MWS-19) (Table 4), which indicates elongated shape of the basin. The elongated

basins are not efficient in run-off discharge as compared to circular basin.

5.2.4 Circularity ratio (Rc): The value ranges from 0.31(MWS-22) to 0.75 (MWS-12) (Table 4). Greater the value more is the circularity ratio. It is the significant ratio which indicates the stage of dissection in the study region. Its low, medium and high values are correlated with youth, mature and old stage of the cycle of the tributary watershed of the region. The Rc value of 0.4 and below indicates basin is elongated and values greater than 0.75 indicate circular basin. Rc values in 0.4-0.75 indicate intermediate shape of basin. Miller (1953) has described the basin of the circularity ratios range 0.4 to 0.5, indicates highly permeable homogenous geologic materials present in the area. The circularity ratio value (0.44) of the watershed corroborates the Miller's range, which indicates that the watershed is elongated in shape, low discharge of runoff and highly permeability of the subsoil condition. In the present study the Rc value of three sub-basins (MWS-15, 19 and 22) falls below 0.4 and only one sub-basin (MWS-26) shows above 0.75. It indicated that majority of the sub-basins are in between elongated and circular in shape.

5.2.6 Drainage density (D_d): Dd is the other element of drainage analysis which provides a better quantitative expression to the dissection and analysis of land forms, although a function of climate, lithology, structures and relief history of the region and can ultimately be used as an indirect indicator to explain those variables, as well as the morphogenesis of landform. Drainage density is defined as the total length of streams of all orders to total drainage area. The drainage density, which is expressed as km/km², indicates a quantitative measure of the average length of the overland flow, and therefore, provides at least some indication of the drainage efficiency of the Low drainage density generally results in the areas of highly resistant or permeable sub-soil material, dense vegetation and low relief. High drainage density is the result of weak or impermeable sub-surface material, sparse vegetation and mountainous relief. Low density leads to coarse drainage texture while high drainage density leads to fine drainage texture. The low value of drainage density influences greater infiltration and hence the wells in this region will have good water potential leading to higher specific capacity of wells. In the areas of higher drainage density the infiltration is less and surface runoff is more. The drainage density can also indirectly indicate groundwater potential of an area, due to its surface runoff and permeability. D_d of the NAKW varies from 0.93 (MWS-23) to 5.02 (MWS-9) (Table 4). MWS are classified based on D_d (Table 5), and found that 48% of the MWS belongs to course textured, 32% belongs to moderate textured and 10%, 6% and 4% belongs to very coarse, fine and very fine textured category respectively.

Table 5: Classification of	MWS based on drainage
density (D ₃) (Smith, 1954)	·

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D_d	Textures	MWS	% of
(km/km ²)			MWS
< 1.24	Very coarse	23,24,30	10
1.24-2.49	Coarse	1,2, 3, 4, 5, 8,15,16, 22, 25,26,27, 28, 29,31	48
2.49-3.73	Moderate	6,7, 10, 11, 13,17,18,19, 20,21	32
3.73-4.97	Fine	12,14	06
> 4.97	Very fine	9	04

5.2.7 Drainage texture (T): The 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 development (Smith, 1950). Amount of soils, which influences the rate of surface runoff, affects the drainage texture of an area (Chopra et al., 2005). The soft or weak rocks unprotected by vegetation produce a fine texture, whereas massive and resistant rocks cause coarse texture. Sparse vegetation of arid climate causes finer textures than those developed on similar rocks in a humid climate. The texture of a rock is commonly dependent upon vegetation type and climate (Darnkamp and King, 1971). The T of the MWS of NAKW is presented in Table 4. Based on the values of T, it classified as (Smith, 1950) is presented in the table 6.

Table 6: Classification of MWS based on drainage texture (T) (Smith, 1950)

T (km/km ²)	Texture	MWS	% of MW S
< 4	Coarse	1,2,3,4,15, 22,23,24,25, 29,30,31	39
4-10	Interme diate	5,6,7,8,16,1926,27, 28	29
10-15	Fine	13,17,18,20, 21	16
Above 15	Ultra Fine	9,10,11,12, 14	16

5.2.8 Texture ratio (Tr): It is an important factor in the drainage morphometric analysis, which depends on the underlying lithology, infiltration capacity and relief aspect of the terrain. Texture ratio for 3rd order MWS of NAKW varies from 0.45 (MWS-30) to 2.55 (MWS-18) (Table 4).

5.2.9 Circularity ratio (Rc): The value ranges from 0.31(MWS-22) to 0.75 (MWS-12) (Table 4). Greater the value more is the circularity ratio. It is the significant ratio which indicates the stage of dissection in the study region. Its low, medium and high values are correlated with youth, mature and old stage of the cycle of the tributary watershed of the region.

5.2.10 Constant of channel maintenance (C_m): It indicates the number of Sq.km of watershed required to sustain one linear km of channel. It not only depends on rock type permeability, climatic regime, vegetation, relief but also as the duration of erosion and climatic history. The constant is extremely low in areas of close dissection. Constant of channel maintenance for NAKW is found to vary between 0.19 (MWS-9) to 1.07 (MWS-23) (Table 4).

5.2.11 Form factor (F_f): The value of form factor would always be greater than 0.78 for a near perfect circular watershed. Smaller the value of the form factor, more elongated will be the watershed. Form factor for MWS of NAKW varies from 0.17 (MWS-15) to 0.46 (MWS-26) for 3^{rd} order basins (Table 3).

5.2.12 Stream frequency (Fs): Horton (1945) introduced stream frequency or channel frequency as number of stream segments per unit area. Stream frequency of NAKW3rd MWS is found to be varying between 0.67 (MWS-30) to 9.51 (MWS-12) (Table 4). Based on stream frequency the MWS are classified and is presented in Table 7.

5.2.13 Elongation ratio (Re): The value ranges from 0.3 (MWS-9,12,14) to 0.16 (MWS-31) for 3^{rd} order MWS (Table 4). Lesser the value more is the elongation of the watershed. Strahler (1952) states that the ratio of Re runs between 0.6-1 over a wide variety of climatic and geologic types. Re Value of 1 are found in typical regions of low relief, while values from 0.6-0.8 are generally associated with strong relief and steep ground slopes.

Table 7: Classification of MWS based on streamfrequency (Fs) (Imran Malik et al., 2011)

nequency	(1.5) (1.111 an 10	ank ci an, 2011)	
Fs (km ²)	Class	MWS	%
Below 2.5/km ²	Poor	1,2,3,4, 5,15,22,23,24 25,29,30,31	42
2.5 to $3.5/\text{km}^2$	Moderate	6,7,8,16, 19,26,27,28	26
3.5 to $4.5/\text{km}^2$	High	17,18,21	10
Above 4.5/km ²	Very High	9,10,11,12,13, 14,20	22

5.2.10 Infiltration Number (If): The infiltration number of a watershed is defined as the product of drainage density and stream frequency and given an idea about the infiltration characteristics of the watershed. The higher the infiltration number, the lower will be the infiltration and the higher run-off. Infiltration number for 3rd order MWS of the study area is presented in the table 4.

5.2.11 Lemniscate ratio (K): Chorely et al. (1957) express the lemniscate's value to determine the slope of the basin. Higher value of laminiscate ratio indicates high runoff and vice-versa. Table 4 shows the K values of 3^{rd} order MWS of NAKW.

5.3 Relief aspects: Relief aspects is an indicator of flow direction of water as it is an important factor in understanding the extent of denundational process that have undergone within the watershed. It comprises of watershed relief, relief ratio, relative relief, ruggedness number. Fig 4 shows DEM of 3rd order sub-watersheds of NAKM.

5.3.1 Watershed relief (R): R is the difference in elevation between the remotest point in the water divide line and the discharge point of the watershed. The difference in elevation between the remotest point and the discharge point is obtained from the available DEM. The highest relief in the watershed is found to be 1451 m above the mean sea level and the lowest relief is 762 m above the mean sea level (Table 8). The overall relief calculated for the watershed is 689 km.

5.3.2 Relief ratio (\mathbf{R}_{f}): \mathbf{R}_{f} is the ratio of maximum watershed relief to the horizontal distance along the longest dimension of the watershed parallel to the principal drainage line (Schumm, 1956). It measures the overall steepness of a watershed and is an indicator of the intensity of erosion processes operating on slopes of the watershed. Overall relief ratio for NAKW is found to vary between 0.903 (MWS-31) to 0.015 (MWS-24) (Table 8) for 3rd order sub watersheds.

5.3.3 Relative relief (Rr): Rr is defined as the ratio of the maximum watershed relief to the perimeter of the watershed. Overall Relative relief ratio for NAKWis found to be vary from 0.005 (MWS-24) 0.378 (MWS-31) (Table 8) for 3^{rd} order sub-watershed.

Table 8: Relief aspects 3 th order sub-watersheds										
	Highest	Lowest	Lowest	R	$R_{\rm f}$	R _r	Sb	R _n	Meltons	
MWS	RL(m)	RL(m)	RL (m)						Ruggeness	
									number	
1	947	763	773	0.174	0.023	0.009	3.26	0.0002	250.34	
2	1036	807	831	0.205	0.068	0.023	25.44	0.0002	543.76	
3	1092	846	863	0.229	0.042	0.016	8.31	0.0003	361.80	
4	987	859	872	0.115	0.024	0.008	5.87	0.0001	338.74	
5	1001	891	923	0.078	0.020	0.007	7.58	0.0001	451.29	
6	1261	893	923	0.338	0.100	0.038	32.60	0.0009	615.30	
7	1350	837	844	0.506	0.097	0.033	19.12	0.0013	473.76	
8	1184	835	844	0.34	0.099	0.038	30.01	0.0007	556.29	
9	1324	893	899	0.425	0.192	0.083	89.05	0.0021	1279.96	
10	1426	809	899	0.527	0.195	0.069	85.27	0.0017	799.66	
11	1451	1144	1165	0.286	0.139	0.051	73.05	0.0010	1109.61	
12	1391	1157	1165	0.226	0.140	0.051	91.41	0.0009	1297.11	
13	1257	871	870	0.387	0.135	0.052	47.86	0.0009	790.27	
14	1309	916	925	0.384	0.188	0.077	95.37	0.0015	1205.03	
15	1129	809	818	0.311	0.035	0.014	4.21	0.0005	312.65	
16	1151	831	840	0.311	0.051	0.018	8.89	0.0007	349.43	
17	1121	836	840	0.281	0.064	0.026	15.13	0.0008	499.33	
18	1124	834	837	0.287	0.048	0.017	8.39	0.0008	342.18	
19	1005	834	837	0.168	0.043	0.018	11.42	0.0004	638.18	
20	1163	881	883	0.28	0.107	0.045	41.72	0.0007	871.71	
21	1011	882	883	0.128	0.058	0.022	27.39	0.0003	751.47	
22	1182	840	841	0.341	0.037	0.012	4.04	0.0005	265.03	
23	1159	857	863	0.296	0.048	0.018	8.12	0.0002	350.73	
24	920	856	863	0.057	0.015	0.005	4.80	0.0003	397.01	
25	999	819	836	0.163	0.022	0.008	3.43	0.0002	232.07	
26	967	822	836	0.131	0.055	0.021	25.81	0.0002	600.86	
27	952	803	818	0.134	0.038	0.015	12.45	0.0003	479.00	
28	953	770	781	0.172	0.033	0.014	7.18	0.0003	363.33	
29	866	760	774	0.092	0.018	0.008	4.49	0.0001	349.77	
30	1022	765	774	0.248	0.034	0.014	5.01	0.0002	296.01	
31	975	738	754	8.996	0.903	0.371	2.39	0.0152	191.92	





5.3.4 Slope: Slope analysis is an important parameter in geomorphic studies. Slope map of the 3^{rd} order subwatersheds are presented in Fig. 5. The slope elements, in turn, are controlled by the climatomorphogenic processes in the area underlying the rocks of varying resistance. An understanding of slope distribution is essential, as a slope map provides data for planning, settlement, mechanization of agriculture, reforestation, deforestation, planning of engineering structures, morpho-conservation practices, etc (Table 8).

5.3.5 Slope gradient (Sg): Sg is one of the main morphological factors controlling drainage density. Sg of 3^{rd} order sub-watersheds of NAKW is presented in Table 8.

5.3.6 Ruggedness number (Rn): High values of the Rn in the watershed are because both the variables like relief and drainage density are enlarged. Extensively high value of ruggedness number occurs for a high relief region with high stream density. Overall ruggedness number for NAKWis found to be 1.184 and ruggedness number maximum in 4th order subwatershed is 1.33 in 4th sub-watershed and minimum is 0.50 in 8th sub-watershed (Table 8).

6. Identification of groundwater potential zones using morphological parameters

Drainage pattern of an area is very important in terms of its groundwater potentiality. It is the source of surface water and is affected by structural, lithological and geomorphological set up of an area (Schumm, 1956). The drainage pattern in the present study area is dendritic in nature. This may be due to more or less homogeneous lithology. In the study area high

drainage density is observed over the hilly terrain with impermeable hard rock substratum, and low drainage density over the highly permeable sub-soils and low relief areas. Low drainage density areas are favourable for identification of groundwater potential zones. Slope plays a very significant role in determining infiltration vs. runoff relation. Infiltration is inversely related to slope i.e. gentler is the slope, higher is infiltration and less is runoff and vice-versa. In the study area gentle slope is all around the periphery of the basin. Low drainage density areas are showing gentler slope in the study area.





7. Conclusion

In the present study, linear, areal and relief morphometric parameters are analysed using GIS techniques. Drainage pattern analysis shows that in the study area all watersheds belong to dendritic type of drainage pattern except MWS-4, which belongs to radial drainage pattern. Based on length of overlaid flow the majority of MWS indicates short flow- paths, with steep ground slopes, reflecting the areas associated with more run-off and less infiltration. The remaining MWSs indicate moderate ground slopes, where the run-off and infiltration are moderate and long flow-paths and gentle ground slopes, which reflect areas of less surface run-offs and more infiltration. Bifurcation ratio indicates absence of any significant structural control on the development of the drainage. The drainage density of NAKW 3rd order sub-watersheds, reveal that the subsurface strata are permeable as majority number of MWS show course D_d (less than 2.49). The study reveals that the drainage areas of the basin are passing through an early mature stage of the fluvial geomorphic cycle. Lower order streams mostly dominate the basin. The elongated shape of the basin is mainly due to the guiding effect of thrusting and faulting. The erosional processes of fluvial origin are predominantly influenced by subsurface lithology of the basin. Relief ratio indicates that the discharge capabilities of some of the MWS are high and in others infiltration is more with good groundwater potential. These studies are very useful for rainwater harvesting and watershed management plans.

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