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Drainage Morphometric Analysis of the Nagavathi Watershed of Dharmapuri District, Tamil Nadu, India Using SRTM Data and GIS

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Abstract: GIS and Remote sensing have proved to be a resourceful tool in the explanation of drainage pattern for water resources management and its planning. The identification of morphometric characteristics based on a Geographic Information System (GIS) was carried out in the Nagavathi watershed, Dharmapuri District. The quantitative drainage morphometric parameters was carried out for the Nagavathi watershed by estimating their (a) Linear aspects like Stream number, Stream order, Stream length, Mean stream length, Stream length ratio, Bifurcation ratio, (b) Aerial aspects like Drainage density, Stream frequency, Texture Ratio, Elongation ratio, Form factor, Circularity index, Length of overflow, Constant of Channel maintenance, Drainage texture, Compactness coefficient and (c) Relief aspects like Basin relief, Relief ratio, Ruggedness number, Gradient ratio, Melton ruggedness ratio, Slope, relative relief, Shape Factor and Leminscate. The drainage area of Nagavithi watershed is 482 sq. Km. the main drainage patterns is dendritic to sub-dendritic drainage. The Nagavathi watershed was classified as a fifth order drainage watershed, whereas micro watershed was classified as an eight in the watershed. Stream order of the watershed was predominantly controlled by structural and lithological controls of various drainage patterns and their stream orientations were identified to evaluate the direction and controlling factors in drainage network. The drainage density in the area has been found to be low which indicates that the area possesses highly permeable soils and low relief. The bifurcation ratio varies from 0.8 to 43.1.

The elongation ratio of Microwatersheds varies from 0.13 to 0.43, indicates Microwatersheds fall under elongated pattern. This study would help the local people to utilize the resources for planning rainwater harvesting and watershed management.

Keywords: ArcGIS, Drainage Parameters, Rainwater harvesting, Stream Order, watershed management.

1. Introduction

The morphometric analysis of any watershed is very useful for all geological, hydrological and groundwater studies and valuable for water conservation and natural resource management at micro level and helpful for the farmer's for selecting an area in the watershed for agriculture (Vishavjeet Singh and Singh 2016). Drainage in any area is a surface expression of the subsurface lithology and prevailing physiographic features. Morphometric analysis of a drainage basin and its associated channel network reflect its hydrogeological behaviour and constitute base for assessment of groundwater resource potential (Venkateswaran et al. 2012; Horton 1932, 1945; Strahler 1952; Melton 1965; Leopold et al. 1964; Cannon 1976; Pakhmode et al. 2003; Gangalakunta et al. 2004). Venkateswaran and Prithiviraj (2016) studied Geomorphology and Morphometric Analysis Used as a significant indicator for groundwater prospects a case study of the kousika manadi sub basin Vaigai River Tamilnadu and Sreedevi et al. (2005) studied drainage characteristics of the Pageru river basin in India using topographical maps and Landsat imagery to delineate groundwater potential zones. The present study is focused on the eight micro watershed of Nagavathi watershed with an aim to understand watershed characteristics. This analysis was done using RS and GIS techniques based on drainage lines as represented over the topographical maps in the Scale 1:50,000.

2. Study areas

Nagavathi watershed is located in part of Dharmapuri district of Tamil Nadu. It lies between latitudes 11°45'N to 12°15' N and 77°30' E to 78°30 E longitudes covering an area of about 482 sq. km (Fig.1). The climate of the Dharmapuri district is generally warm.

3. Materials and Methods

Geological Survey of India (GIS) topographical maps of 1:50,000 scale were used to prepare (i) Base maps, (ii) Drainage maps of Nagavathi watershed of Cauvery river basin, Tamil Nadu. The drainage maps are presented in Fig.2. Stream network for the above watershed are traced and scanned. The scanned stream network map was geo referenced and converted into digital format using ArcGIS 9.3 version GIS software. The data used in this study include 30m resolution Digital Elevation Model (DEM) of the basin extracted from the Shuttle Radar Topographic Mission (SRTM) downloaded from the US Geological Survey Website. Quantitative morphometric analysis was carried out for eight in the watershed as mentioned above for linear aspects, areal aspects and relief aspects. The analysis was carried out using ArcGIS software. The drainage network generated was then analysed using Horton (1945), Strahler (1964), Smith (1950), Schumm (1956), etc. for various parameters. The methodologies adopted for the basic parameters have been derived and extracted using various mathematical equations Table 1.

Table 1 Morphometric parameters and their mathematical expressions

S.No	Parameter	Formula	Previous Work
Linear Aspect			
1. 1	Area (A)	Area of the watershed	Horton (1945)
2.	Perimeter (P)	The perimeter is the total length of the watershed boundary.	Miller (1953)
3.	Length (Lb)	Maximum length of the watershed	Horton (1945)
4.	Stream Order (Nu)	Hierarchical rank	Strahler (1957)
5.	Stream Length(Lu)	Length of the stream	Horton (1945)
6.	Stream length ratio (Rl)	$Rl = Lu / Lu\text{-}1$	Sreedevi et al. (2005)
7.	Mean Stream Length Ratio (Lsm)	$Lsm = Lu/Nu$	Horton (1945)
8.	Bifurcation ratio (Rb)	$Rb = Nu / N (u + 1)$	Schumm (1956)
Areal Aspect			
9.	Drainage density (Dd)	$Dd = \sum Lu/A$	Horton (1945)
10.	Stream frequency (Fs)	$Fs = \sum Nu/A$	Horton (1945)
11.	Texture Ratio	$T = Nu/P$	Horton (1945)
12.	Elongation ratio (Re)	$Re = 1.128 \sqrt{A} / L$	Schumm (1956)
13.	Form factor (Ff)	$Ff = A / Lb^2$	Horton (1945)
14.	Circularity index (Rc)	$Rc = 4\pi A / P^2$	Miller (1953) Strahler (1964)
15.	Length of overflow (Lg)	$Lg = 1/2/2d$	Horton (1945)
16.	Constant of Channel maintenance (Ccm)	$C = 1/ Dd$	Schumm (1956)
17.	Drainage texture (T)	$T = Dd \times Fs$	Smith (1950)
18.	Compactness coefficient (Cc)	$Cc+ 0.282\ P / \sqrt{A}^{0.5}$	Gravelius (1914)

Relief Aspect			
19.	Basin relief (R)	R = H – h	Schumm (1956)
20.	Relief ratio (Rr)	Rr = R / L	Schumm (1963)
21.	Ruggedness number (*Rn*)	$Rn = R \times Dd$	Schumm (1956)
22.	Gradient ratio (*G*r)	$Gr = (H\text{-}h)/L$	Sreedevi et al. (2005)
23.	Melton ruggedness ratio (MRn)	$MRn = (H\text{-}h)/A^{0.5}$	Melton (1965)
24.	Slope (Sb)	Sb = H-h / L	Verstappen (1983)
25.	Relative relief (Rhp)	Rhp = H/P x100	Schumm (1963)
26.	Shape Factor (Rf)	$Rf = Lb^2/A$	Nookaratnam et al. (2005)
27.	Leminscate(K)	$K = Lb^2/4x\ A$	Chorely (1967)

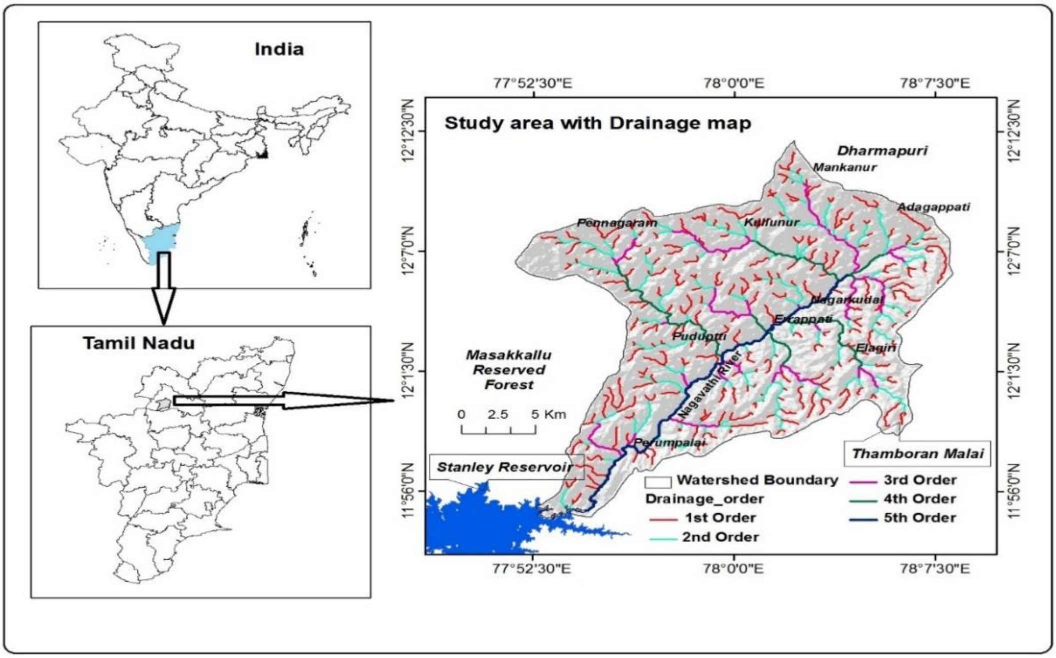

Fig.1 Study area with Drainage map of the Nagavathi watershed

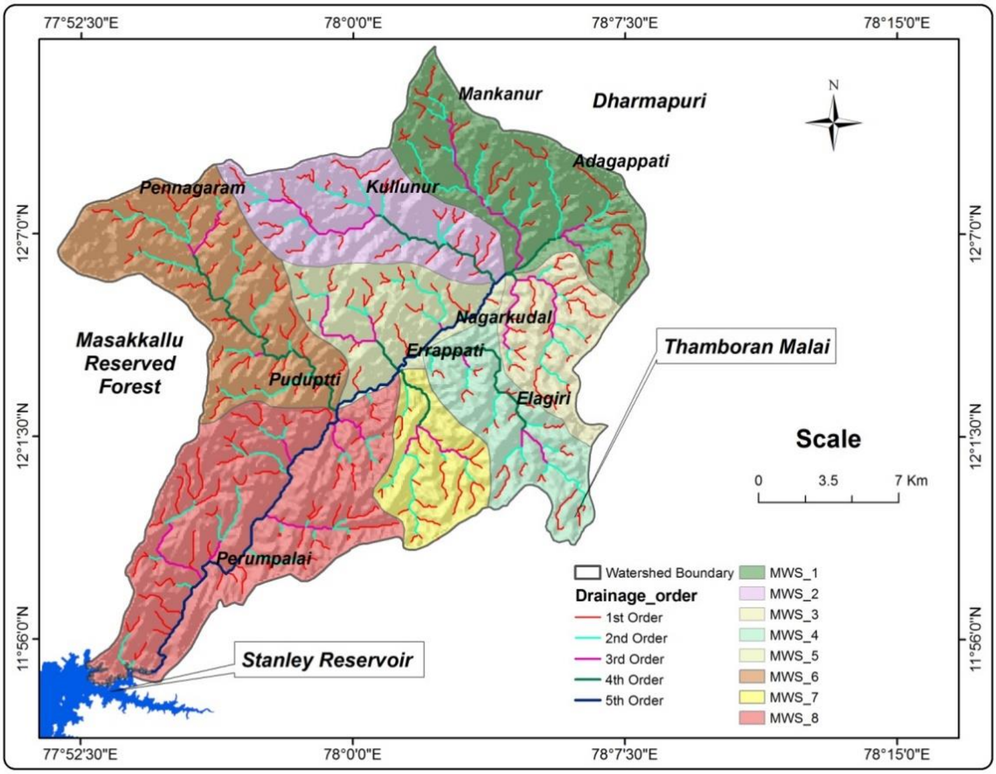

Fig.2 Drainage and Microwatershed – Map

4 Results and Discussion

Further, systematic description of the geometry of the drainage requires measurement of Linear, Aerial and Relief aspects of the channel network, which are discussed below.

4.1 Linear Parameters

4.1.1 Area (A)

The entire area was considered between the divide line and the outfall with all sub and inter-basin areas. The total drainage area of Nagavathi watershed is 481.36 Sq.km, and the areas of each watershed.

4.1.2 Perimeter (P)

The perimeter is the total length of the drainage watershed boundary. The P of the eight Micro watersheds is shown in Table 2. MWS08 has the higher value (P>66.03 km), while the perimeter of MWS07 is less (P<24.39km) than the other micro watershed.

4.1.3 Length of the Basin (Lb)

The basin length is the longest part of the basin parallel to the principal drainage line defined by Schumm (1956). The equation Schumm (1956) used for calculation of stream length that is 324.23 km (Table 2).

4.1.4 Stream Direction

The stream direction has been computed to understand the surface flowing pattern for the surface water development. The length and its direction of each drainage line have been calculated in GIS environment and the values are plotted in Rockworks software for each all micro watershed, presented in Fig 3 and Fig 4.

The stream tributary directions and the local tectonic regime, the stream channels of the Nagavathi micro watershed were grouped according to their order (1-5) and eight rose diagrams were created for each watershed. The major and minor lineament, that is upstream and downstream sections of the watershed, respectively. The watershed in northeast-southwest direction with micro watersheds like MWS01, MWS06 and MWS08.

The lineament crosses the watershed in a southwest-northeast direction and MWS02, MWS03, MWS04, MWS05, and MWS07 in the Microwatershed. In the all micro watershed the dominant direction for maximum streams order is NE-SW and all direction in the micro watershed.

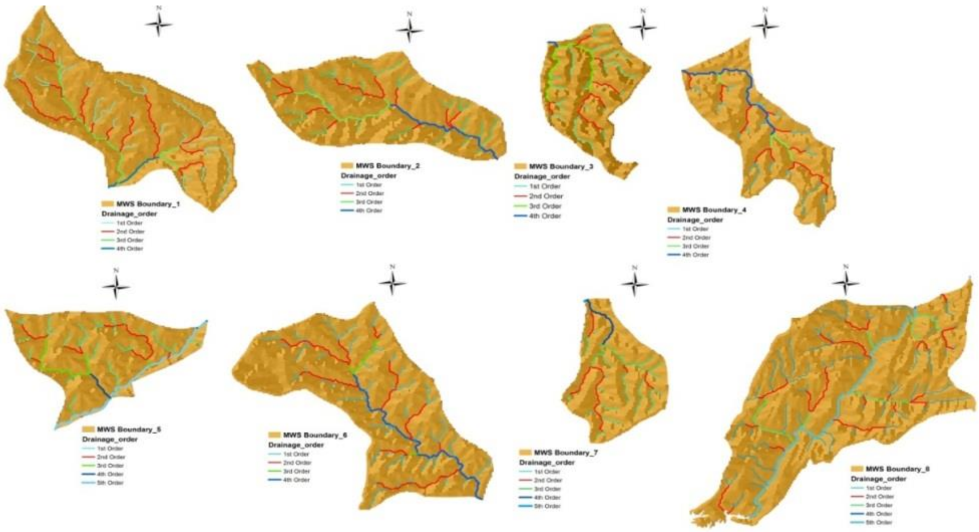

Fig.3 Micro watershed–Map

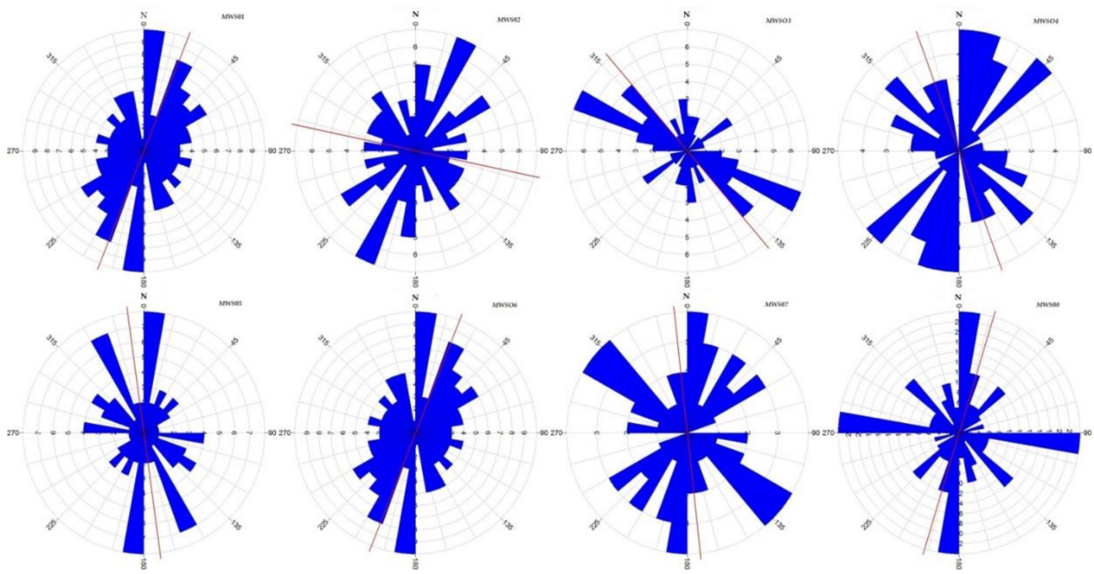

Fig.4 Rose diagrams show the geometry of the Streams Direction and Length

4.1.5 Stream Order (Nu)

There are four different system of ordering streams that are available (Gravelius1914; Horton 1945; Strahler 1952). The 513 numbers of streams were identified and from which 317 are first order streams, 159 are second order, 25 are third order, 9 in fourth order and 3 are fifth order. Drainage patterns of stream network from the basin have been observed as mainly of dendritict type which indicates the homogeneity in texture and lack of structural control. The properties of the stream networks are very important to study watershed characteristics.

4.1.6 Stream Length (Lu)

Stream length is measured from the farthest drainage divide to the mouth of a river, based on the law proposed by Horton (1945). Stream length is one of the important qualities of the watershed as it reveals surface run-off characteristics. Streams of comparatively smaller lengths indicate that the area is with high slopes. Longer lengths are indicative of flatter gradient. Generally, the total length of stream segments is highest in first order streams, and it decreases as the stream order increases in the present case.

4.1.7 Bifurcation Ratio (Rb)

Bifurcation Ratio (Rb) is calculated by dividing the number of streams in the lower by the number in the higher of the two orders. For watershed the Rb is showing the range between 0.8 to 43.1, in the study mean bifurcation ratio (Rbm) is 8.3 which suggest less geological heterogeneity, higher permeability and lesser structural control in the area.

4.2 Areal Aspect

The areal aspect is the two dimensional properties of a basin. Watershed area directly affects the size of the storm hydrograph, the magnitudes of peak and mean runoff and results have been given in Table 2

4.2.1 Drainage Density (D)

Drainage density is termed as the total length of streams of all order per drainage area and indicates the closeness of the spacing of channels (Horton 1932). The Drainage density in the watershed is low and varies from 0.1 to 1.7 km/ km2, thus indicates clearly that region has highly slope, rock types, dense vegetation cover, soil texture, and runoff intensity. The amount of precipitation and slope gradient directly influences the quality and characters of surface runoff.

4.2.2 Stream Frequency (Fs)

Stream frequency (Fs) is the total number of stream segments of all orders per unit area (Horton 1932). This is reflected in this study too with stream frequency ranging from 0.9 to 1.3 while in micro watersheds 1 and 8, respectively. It is observed that there is a decrease in stream frequency as the stream order increases. The values micro watersheds 1 and 8 takes longer time to peak and have less runoff rates when compared to others. Micro watersheds are preferred for conservation activities based on their decreasing order of stream frequency.

4.2.3 Texture Ratio (T)

Drainage texture ratio (T) is the total number of stream segments of all orders per perimeter of that area (Horton, 1945). It depends upon a number of natural factors such as climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief and stage of development. In the present study the texture ratio of the basin is 1.21 and categorized as good in the nature.

4.2.4 Elongation Ratio (Re)

Schumm (1963) used an elongation ratio (Re) defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. It is a very significant index in the analysis of basin shape which helps to give an idea about the hydrological character of a drainage basin. Values near to 0.6 are typical of regions of very low relief (Strahler, 1964). The value Re of the study area is 0.13 indicates that the low relief of the terrain and elongated in shape.

4.2.5 Form Factor (Ff)

Rf is the ratio of basin area to square of the basin length and is a quantitative expression of drainage basin outline (Horton 1932). There is a low form factor in a basin that indicates less intense rainfall simultaneously over its entire area than an area of equal size with a large from factor. It ranges from factor 0.13 to 2.52

4.2.6 Circularity Ratio

Circularity ratio (Rc) is influenced by the length and frequency of streams, geological structures, drainage pattern, relief and slope of the watershed (Strahler 1957; Srinivasa et al. 2004). The range of Rc in the study area varied between 0.29 and 0.68. Maximum value was observed in MWS07, and minimum value was observed in MWS05, Which indicates that they are more or less circular. They are characterised by high to moderate relief and drainage system is structurally controlled.

4.2.7 Length of Overland Flow (Lg)

Over land area is clear as half of the reciprocal of drainage density. It is one of the most important independent variables, affecting both the hydrological and physiographical developments of the drainage basin (Horton 1945). The value of Lg for micro watersheds varied from 0.29 to 8.56. Results obtained during the study reveals that the minimum value of Lg was found in MWS01, MWS02 and MWS07 as drainage density is high in these three sub-watersheds when compared with remaining micro watersheds.

4.2.8 Constant of Channel Maintenance (1/D)

Schumm (1956) used the inverse of drainage density as a property termed constant of stream maintenance C. This constant, in units of square feet per foot, has the dimension of length and therefore increases in magnitude as the range of the landform unit increases. Specifically, the constant C provides information of the number of square feet of watershed surface required to sustain one linear foot of stream. The value C of basin is 3.7.

4.2.9 Drainage Texture (Rt)

Rt is one of the main concepts of geomorphology, which means the relative spacing of drainage lines. Drainage lines are numerous over impermeable areas than permeable areas. It is the total number of stream segments of all orders per perimeter of that area (Horton 1945). According to Smith (1950), five different classes of drainage textures can be made based on the drainage density. The values of Rt for the micro watershed ranged from 1.1 to 2.3 (Table 2), which indicates very coarse to coarse drainage texture. The Drainage texture of watershed depends on climate, rainfall, vegetation, soil and rock types, infiltration rate, relief and the stages of development.

4.2.10 Compactness Coefficient (Cc)

It can be represented as basin perimeter divided by the circumference of a circle to the same area of the basin and also known as the Gravelius Index (GI). This factor 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, while higher values indicate the less elongation and high erosion. In this study, highest value is 1.73 while the lowest is 1.21 shown in Table 2

4.3 Relief aspects

The relief aspects of the drainage basins are significantly related with the study of three dimensional features linking area, quantity and height above sea level of vertical dimension of landforms to analyzed different hydrogeological features. Some of the significant relief parameters that are associated to the study have been analysis as shown in Table 2.

4.3.1 Basin Relief (R)

Basin relief (R) is an important factor to understand denudational characteristics of the basin, which controls the stream gradient and therefore influences the flood pattern and the amount of sediment transported (Hadley and Schumm, 1961). The lowest relief of 58 m is observed in the plains and highest of 892m in the mountainous areas.

4.3.2 Relief Ratio (Rr)

Relief ratio is elevation difference of lowest and highest points of watershed, and the longest dimension of the basin parallel to the principal drainage line (Schumn 1956). Relief ratio of the studied watershed is 892 m, whereas that of the watershed vary from 6.4 (MWS01) to 75.0 (MWS08) and thus indicates high relief ratio and moderate to low relief ratio (Table 2).

Table 2 Linear, Areal and Relief aspects of Nagavathi watershed

S. No	Parameter		MWS 01	MWS 02	MWS 03	MWS 04	MWS 05	MWS 06	MWS 07	MWS 08
Linear Aspect										
1	Area (A)		72.18	58.76	33.35	42.14	43.43	82.79	32.26	116.45
2	Perimeter (P)		42.21	36.27	27.83	35.45	43.43	46.39	24.39	66.03
3	Micro Watershed Length (LW)		7.26	7.56	6.23	3.16	10.71	7.04	6.16	21.55
4	No. of Stream Order (Nu)		67	53	38	43	47	78	36	151
5	Stream Length (Lu) km		78.86	61.49	40.85	44.64	54.27	75.71	40.51	128.28
6	Stream Length Ratio (Rl)	II/I	0.63	0.45	0.43	0.67	0.66	0.47	0.36	0.96
		III/II	0.11	0.13	0.2	0.22	0.27	0.11	0.17	0.24
		IV/III	0.08	0.14	0.11	0.26	0.13	0.25	0.19	0.13

		V/IV	0	0	1.67	0	0.49	0	0.25	20
7	Mean Stream Length Ratio (Lsm)		4.5	4.1	43.1	4.8	1.8	4.2	3.2	0.8
8	Bifurcation Ratio (Rb)	I/II	2.9	3.6	3.9	3.3	3	3.7	4.6	2.3
		II/III	8.3	8	5.5	5	5.7	7.7	4.5	9.7
		III/IV	4	3	3	4	4	4	3	4.5
		IV/V	0	0	0	0	2	0	2	3
Areal Aspect										
9	Drainage density (Dd)		1.1	1	0.5	0.5	0.2	0.9	1.7	0.1
10	Stream frequency (Fs)		0.93	0.9	1.14	1.02	1.08	0.94	1.12	1.3
11	Texture Ratio		0.97	0.99	0.93	0.76	0.64	1.16	1.03	1.21
12	Elongation ratio (Re)		0.13	0.14	0.27	0.25	0.38	0.13	0.15	0.43
13	Form factor (Ff)		0.01	0.02	0.1	0.1	0.55	0.01	0.01	2.52
14	Circularity index (Rc)		0.51	0.56	0.54	0.42	0.29	0.48	0.68	0.34
15	Length of overflow (Lg)		0.46	0.48	0.93	1.02	2.44	0.55	0.29	8.56
16	Constant of Channel Maintenance (Ccm)		0.92	0.96	1.86	2.05	4.88	1.11	0.58	17.13
17	Drainage texture (T)		1.6	1.5	1.4	1.2	1.1	1.7	1.5	2.3
18	Compactness coefficient (Cc)		1.4	1.33	1.36	1.54	1.86	1.44	1.21	1.73
Relief Aspect										
19	Basin relief (R)		500	517	500	892	515	537	540	510
20	Relief ratio (Rr)		6.4	8.4	27.9	43.3	57.9	7.2	9.8	75
21	Ruggedness number (Rn)		545.16	539.35	268.52	436.05	105.54	485.17	924.33	29.78
22	Gradient ratio (Gr)		6.4	8.4	27.9	43.3	57.9	7.2	9.8	75
23	Melton Ruggedness ratio (MRn)		58.9	67.4	86.6	137.4	78.1	59	95.1	47.3
24	Basin Slope (Sb)		18.7	20.8	21.3	16.8	3.9	0.5	0.6	3.6
25	Relative relief (Rhp)		11.85	14.25	17.97	25.16	11.86	11.58	22.14	7.72

26	Shape Factor (Rf)	85.81	63.95	9.62	10.07	1.82	67.58	94.52	0.4
27	Leminscate(K)	21.45	15.99	2.4	2.52	0.46	16.9	23.63	0.1

4.3.3 Ruggedness number (Rn)

Ruggedness number (Rn) indicates structural complexity of the terrain relief, drainage density and the area susceptible to soil erosion (Sameena et al., 2009). The Rn of the watershed is showing low value 29.78m indicating low basin relief. Rn of the watershed, ranges from 29.78m (MWS08) to 924.33m (MWS07) suggest low relief and poor drainage density.

4.3.4 Gradient Ratio (Rg)

Gradient ratio (Rg) is an indication of the channel slope from which the runoff volume could be evaluated (Sreedevi, 2004). The altitude of the channel surface of the Nagavathi watershed stream averagely falls at the rate of 29.48 m/km in the downstream direction. In the actual field the greatest fall is observed in the structural hills areas dominated by lower order streams and least in the plains occupied. It means that the mean channel slope decreases with increasing order number.

4.3.5 Melton Ruggedness Number (MRn)

The MRn is a slope index that provides specialized representation of relief ruggedness within the watershed (Melton 1965). The MRn of Nagavathi watershed is 86.6 and that of the watershed vary from 47.3 to 137.4 (Table 2).

4.3.6 Basin slope (Sb)

The slope of a terrain to the amount of inclination of physical feature, landform is the horizontal surface. Slope analysis is an important parameter in morphometric studies. The slope elements, in turn are controlled by climate morphogenic processes in areas having rock of varying resistance (Burrough (1986). The Sb of Nagavathi watershed is ranging from 0.5 to 21.3, revealing the moderate to highly sloping terrain characteristic of the naturally occurring in undulated terrain

4.3.7 Relative Relief (Rhp)

The Rhp is an important morphometric variable used for the overall assessment of morphological characteristics of terrain. Melton (1957) suggested a method to calculate Rhp by dividing the h with p. There are three categories of Rhp viz (i) low = 0 m – 1 m, (ii) moderate = 1 m – 3 m and (iii) high = above 3 m. The Rhp of the Nagavathi watershed is 75.0 and therefore, the watershed has a low and high relative relief.

4.3.8 Shape Factor (Bs)

The shape factor can be defined as the ratio of the square of the basin length to area of the basin (Horton 1945) and is in inverse proportion with form factor (Rf). Shape factor lies between 0.40 to 94.52 in present work, which indicates the elongated shapes of watershed.

4.3.9 Lemniscate (k)

Chorely et.al. (1957), express the lemniscate value to determine the slope of the basin. The lemniscate (k) value for the watershed is 0.10 to 21.45 respectively.

5 Conclusions

Morphometric analysis and classification of 8 micro watershed related to the Nagavathi watershed were implemented using GIS techniques. GIS based approach facilitates analysis of different morphometric parameters and to explore the relationship among the drainage basin morphometry and topographical, geological, lithological, structural and hydrological aspects. Micro watersheds show dendritic to sub dendritic drainage pattern with moderate drainage texture. Twenty seven (27) morphometric parameters of the watershed were estimated and hydrological inferences were made. The landforms represented by the lineament pattern reflect the inner geological architecture of the area, including the major trends of the dominant direction for maximum streams order is NE-SW and all direction in the micro watershed. Drainage density, texture ratio, circulatory ratio and elongation ratio shows that texture of watershed is moderate and shape of basin almost elongated. High bifurcation ratios indicate a strong structural control on the drainage. The complete morphometric analysis of drainage watershed indicates that the given area is having good groundwater prospect. The formulae used for evaluating morphometric parameter are tabulated in Table 1. Results of this analysis are tabulated in Table 2.

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