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Morphometric Analysis of Shanthanavardhini Watershed using GIS

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Abstract – Morphometric analysis was carried out to estimate the characteristics of a watershed. Earlier this analysis was laborious and time consuming as they were performed manually. The advent of satellite image and Geographical Information System (GIS) had made the analysis easier. For the present study Shanthanavardhani watershed located in Dindigul District, Tamil Nadu, India was selected. The geographical area of the watershed was 71.85 Km2. Morphometric parameters were analysed in three different aspects viz., linear, relief and areal. The watershed falls in 5th basin order, the basin relief is 0.82 Km, ruggedness number is 2.19. The value of drainage density, bifurcation ratio and stream frequency of the watershed is 2.68, 3.48 and 5.07 respectively. The output of the analysis can be used for further study such as identification sites for constructing water harvesting structure, estimation of soil erosion etc.

Keywords— GIS, satellite image, watershed, morphometric parameters, drainage density

I. Introduction

Morphology of a region explains shape and its other related characteristics, which is very much needed to understand the nature of the region and temporal changes happening in the region over a period of time. There are a number of characteristics grouped under linear, relief and areal parameters. When these morphological parameters analysed with hydrological parameters, they help in the assessment of underground water resources and also estimation of these resources. In addition, the output of the morphometric analysis can be used for identification of sites for constructing various water harvesting structures, areas of erosion etc.

Earlier the analysis of these parameters was mainly carried out manually which used to be laborious and cumbersome. After the advent of GIS and availability of satellite data made the analysis easier and deeper analysis can be performed over large area in lesser time.

Area chosen for the present study is Shantanavardhani watershed located in Dindigul District, Tamil Nadu, India. The geographical extent of the watershed is 78°1’39” E to 78°8’5”E longitude and 10°10’23”N to 10°17’13”N latitude. Total area of the watershed is 71.85 Km^2.

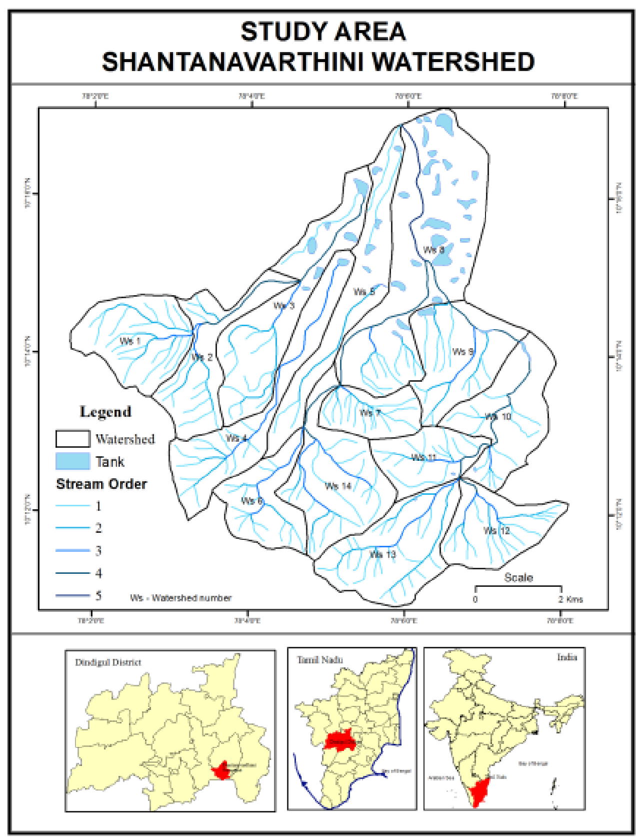

Figure 1: Study Area

II. RELATED WORK

Tribhuvan and et al., studied the morphometric parameters of Phulambri river basin. The result revealed that the rock structure of the region is good for water holding capacity; hence, this study outcome might be useful for ground water investigation [1]. Morphometric parameters of Vrishabhavathi watershed is carried out by Aravinda and Balakrishna. The output of the study helps in comparison of the selected watershed with neighbouring watersheds for making decisions on land and water resource management [2]. Farrukh Altaf et al., studied the morphometric parameter of 17 watersheds in Lidder watershed. The final outcome showed that all these 17 watersheds are vulnerable to flood and flood risk in the downstream regions. Thus stu and et al., analysed the morphometric parameter of Doddahalla watershed and its sub-watersheds. After analysing the parameters they found that transportation of salt increased the salt concentration, water logging and rise in water table [4]. Kuldeep Pareta et.al., used Aster data for conducting a detailed morphometric study of Karawan watershed in Yamuna Basin. Nearly 85 morphometric parameters have been executed. The output of the study can be utilized for watershed management through construction of various water harvesting structures [5].

III. METHODOLOGY

The data used for the present study were Survey of India Toposheets bearing numbers 58 J/3 and 58 J/4 of 1:50,000 scale.

The toposheets were georeferenced in ArcGIS and mosaic in ERDAS Imagine. A Geodatabase and dataset was created and feature classes such as stream, watershed, sub-watershed and tank were created. Using the feature classes, the respective features were digitized. The stream order was added as attribute information to streams, similarly watershed area, perimeter and maximum length of the watershed parallel to major stream were estimated for watersheds. The streams were dissolved based on stream order and the following morphometric parameters were estimated.

Table – 1. Linear Aspect

Morphometric Parameters	Methods
Stream order (U)	Hierarchical order [6]
Stream length (Lu)	Length of the stream in each order [7]
Mean stream length (Lsm)	Lsm = Lu/Nu; [7] where, Lu=Stream length of order 'U' Nu=Total number of stream segments of order 'U'
Stream length ratio (Rl)	Rl=Lu/Lu-1; [7] where Lu=Total stream length of order 'U', Lu-1=Stream length of next lower order.
Bifurcation ratio (Rb)	Rb = Nu/ Nu+1; [6] where, Nu=Total number of stream segment of order'u'; Nu+1=Number of segment of next higher order

Using the area, perimeter and length of the watershed, the areal aspects of the watershed were calculated.

Table 2: Areal Aspect

Morphometric Parameters	Methods
Drainage density (Dd)	Dd = L/A; [7] where, L=Total length of streams;A=Area of watershed
Stream frequency (Fs)	Fs = N/A; [7] where, N=Total number of streams; A=Area of watershed
Texture ratio (T)	T = N1/P; [7] where,N1=Total number of first order streams; P=Perimeter of watershed
Form factor (Rf)	Rf=A/(Lb) 2 ; [7] where, A=Area of watershed, Lb=Basin length
Circulatory ratio (Rc)	Rc=4πA/P2 ; [8] where, A=Area of watershed, π=3.14, P=Perimeter of watershed
Elongation ratio (Re)	Re=2√(A/π)/Lb; [9] where, A=Area of watershed, π=3.14,Lb=Basin length
Length of overland flow (Lof)	Lof = 1/2Dd; [7] where,Dd=Drainage density
Constant channel maintenance (C)	Lof = 1/Dd; [7] where, Dd=Drainage density

The linear and areal aspects were calculated for sub-watersheds also. Finally the relief aspect of the watershed was found using the following formula.

Table 3: Relief Aspect

Morphometric Parameters	Methods
Basin relief (Bh)	Vertical distance between the lowest and highest points of watershed. [9]
Relief ratio (Rh)	Rh=Bh/Lb; [9] Where, Bh=Basin relief;Lb=Basin length
Ruggedness number (Rn)	Rn = Bh × Dd; [9] Where, Bh =Basin relief; Dd=Drainage density

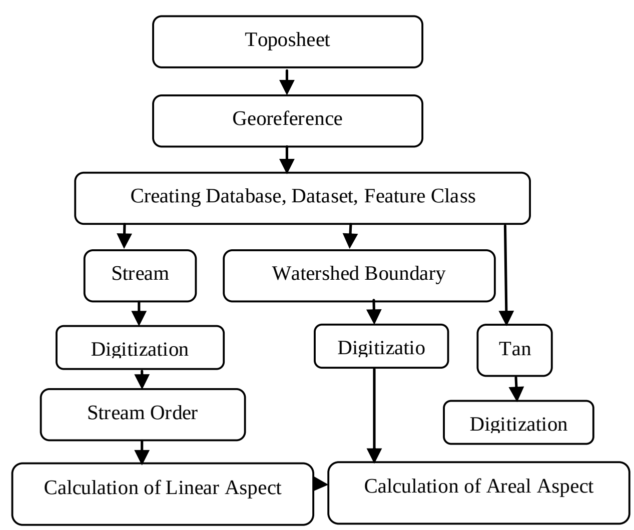

Figure 2: Flow Chart

Prioritization of sub-watersheds was carried using the following formula [10]. The calculation was carried out in attribute table of sub-watershed.

Prioritization = (Drainage density x 0.3) + (Bifurcation ratio x 0.25) + (Stream frequency x 0.2) + (Texture ratio x 0.15) + (Length overland flow x 0.1) + (Constant channel maintenance x 0.05)

IV. RESULTS AND DISCUSSION

Table 4: Output of Linear Aspect

Morphometric Parameters	Results				
Stream Order	I	II	III	IV	V
Stream order (U)	186	100	52	24	3
Stream length (Lu) (Km)	111.13	36.84	23.76	18.40	3.61
Mean stream length (Lsm) (Km)	0.60	0.37	0.46	0.77	1.20
Stream length ratio (Rl)	-	0.33	0.65	0.77	0.20
Bifurcation ratio (Rb)	1.86	1.92	2.17	8.00	-

Table 4: Output of Areal and Relief Aspects

Morphometric parameters	Result
Area (km2)	71.850
Perimeter (km)	41.499
Basin order	5.000
Basin length(Lb)(km)	11.120
Relief ratio (Rh)	0.070
Basin relief (Bh)(km)	0.820
Ruggedness number(Rn)	2.194
Bifurcation ratio(Rb)	3.480
Drainage density(Dd) (km2)	2.675
Stream frequency(Fs) (km2)	5.066
Texture ratio(T) (km)	8.771
Form factor (Rf)	0.581
Circulatory ratio (Rc)	0.524
Elongation ratio (Re)	0.724
Length of overland flow (Lof) (km)	0.187
Constant channel maintenance(C) (km)	0.374

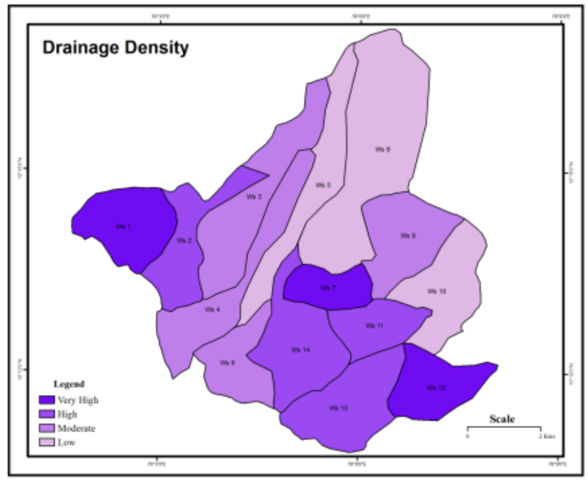

Figure 3

Climate, vegetation type, soil, geology and geomorphology of a region decides the characteristics of drainage density. It is the total length of all streams (L) per unit area (A) of the watershed (Dd=L/A). High impermeable rate, barren rocks or high relief leads to high surface runoff, resulting in high sediment deposition. Thus these regions require more concentration. Porous rocks and permeable soil allows water to percolate, thus leading to low drainage density.

Figure 3 shows the drainage density of Shantanavardhani watershed. Sub-watersheds 1, 7 and 12 have very high drainage density whereas sub-watersheds 5, 8 and 10 have low drainage density.

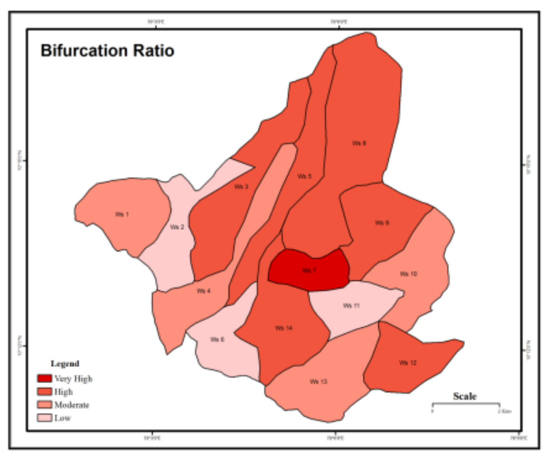

Figure 4

Bifurcation ratio (Bf) is used to find the stream size based on the hierarchy of the tributaries in a stream network. It is first developed by Horton and Strahler. They stated that bifurcation ratio is the ratio between the number of streams in considered order to the streams in next higher order. Finally the mean value is found. Higher the bifurcation ratio, the surface run off and sediment deposition will be more and infiltration rate will be less in these regions. Whereas if the value is low then there will be more infiltration rate and that watershed is less affected by disaster.

Bifurcation ratio of the study area is shown in figure 4. The ratio is very high in sub-watershed 7 and low in sub-watersheds 2, 6 and 11. Thus these low bifurcation ratio sub-watersheds are less affected. Sub-watershed 7 needs more attention.

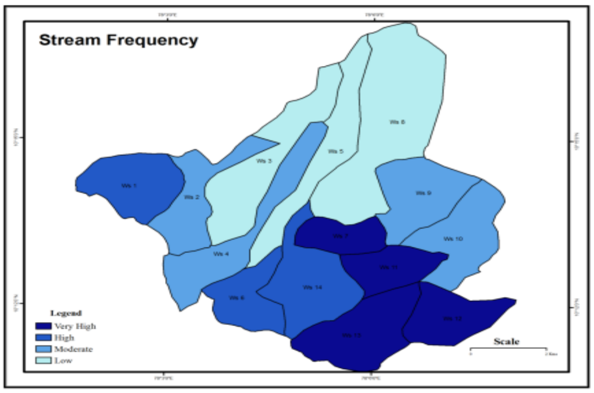

Figure 5

Stream Frequency (Fs) is the ratio between total number of streams (N) and area of the watershed (A). Thick vegetation cover, namely forest, shows low Fs rate and thin vegetation cover such as cultivable land have high Fs rate [11]. High frequency results in high surface runoff.

Stream frequency of the Shantanavardhani watershed is portrayed in figure 5. High stream frequency is found in sub-watersheds 7, 11, 12 and 13; and low frequency rate is traced in sub-watersheds 3, 5 and 8.

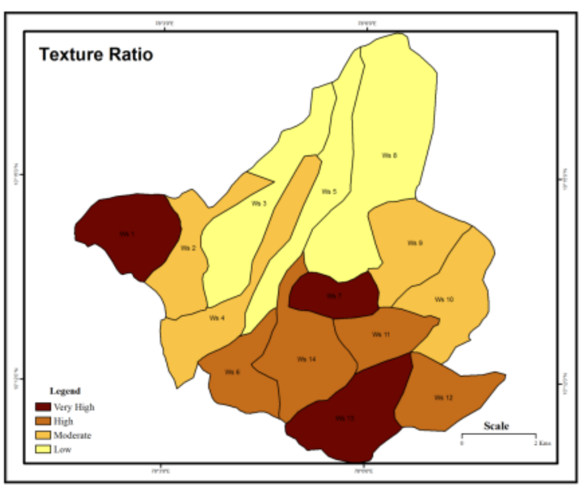

Figure 6

Texture ratio is one of the important parameter in drainage analysis. It depends on the geological structure of the region. It is estimated by dividing total number of first order by perimeter of the watershed. Figure 6 portrays the texture ratio of the study area. High texture ratio is seen in sub-watersheds 2, 7and 13. Sub-watersheds 3, 5 and 8 shows low texture ratio.

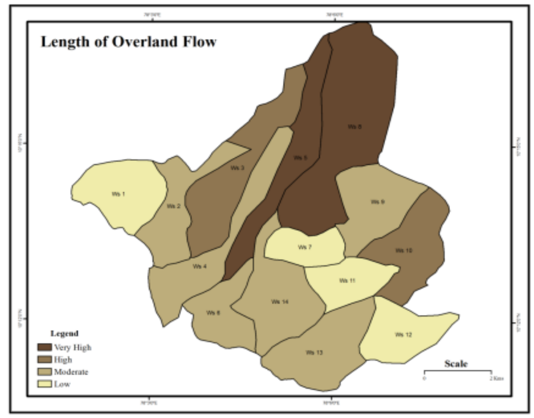

Figure 7

Length of overland flow is first described by Horton. If rainfall exceeds the infiltration capacity of the land, then the water tends to flow horizontal across the land, this is termed to be overland flow. It is half of the drainage density (1/2*Dd). Length of overland flow of the present watershed is shown in figure 7. Overland flow is very high in sub-watersheds 5 and 8 and low in 1,7,11 and 12.

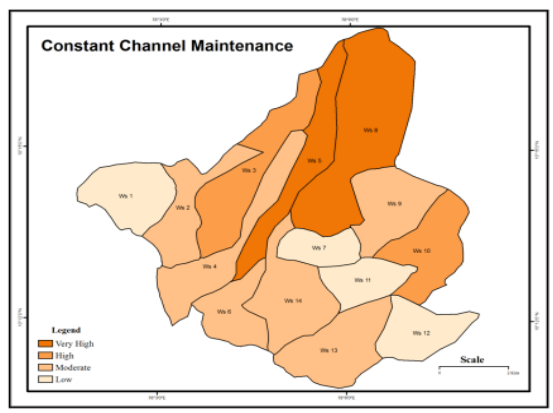

Figure 8

Constant Channel Maintenance (C) is introduced by Schumm. C is the ratio of area and total length of streams or it is the inverse of drainage density (1/Dd). In this study, sub-watersheds 5 and 8 have high C value and sub-watersheds 1, 7, 11 and 12 have low C value (figure 8).

Table 5: Prioritization of Sub-Watersheds

Sub-Watershed ID	Bf	Dd	Fs	T	Lof	C	Priority
Ws 1	2.05	3.68	6.60	1.90	0.14	0.27	Low
Ws 2	1.61	3.16	5.53	0.81	0.16	0.32	High
Ws 3	2.56	2.44	3.06	0.60	0.20	0.41	Very High
Ws 4	1.71	2.74	5.06	0.84	0.18	0.37	High
Ws 5	2.50	1.87	1.18	0.28	0.27	0.54	Very High
Ws 6	1.21	3.00	7.38	1.49	0.17	0.33	Moderate
Ws 7	5.22	4.38	9.67	1.98	0.11	0.23	Low
Ws 8	2.34	1.67	2.36	0.22	0.30	0.60	Very High
Ws 9	3.02	2.97	4.76	1.24	0.17	0.34	High
Ws 10	1.83	2.20	5.09	1.14	0.23	0.45	High
Ws 11	1.58	3.52	8.48	1.58	0.14	0.28	Moderate
Ws 12	2.83	3.68	7.87	1.78	0.14	0.27	Low
Ws 13	1.92	3.39	8.63	2.32	0.15	0.30	Moderate
Ws 14	2.87	3.29	6.39	1.42	0.15	0.30	Moderate

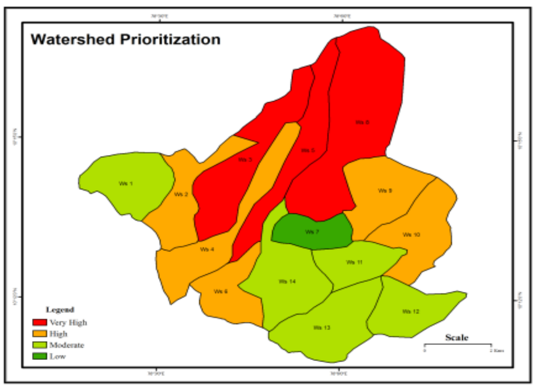

Figure 9

Figure 9 portrays the prioritized map of the Shantanavardhani watershed. Very High priority has to be provided to sub-watersheds 3, 5 and 8; followed by 2,4,6,9 and 10. Sub-watershed 7 needs the lowest priority.

V. Conclusion

Various morphologic parameters of Shanthanavardhani watershed have been estimated using ArcGIS with the use of toposheet. The parameters include bifurcation ratio, drainage density, stream frequency, texture ratio, length of overland flow, constant channel maintenance etc., for prioritization of sub-watersheds. The values of drainage density, bifurcation ratio and stream frequency are high in sub-watershed 7. From the prioritized map it is clear that sub-watersheds 3,5 and 8 needs very highest priority.

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Authors Profile

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