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A GIS-Based Approach in Drainage and Morphometric Analysis of Suvarnavathi River Basin and Sub-watersheds, Karnataka, India

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Abstract: The present case study describes the morphometric analysis and its influence on the hydrology of the Suvarnavathi river basin and its sub-watersheds. ALOS DEM is used to extract slope and drainage layers while GIS software is used in the evaluation of linear, areal and relief aspects of morphometric parameters for 13 sub-watersheds of the entire river catchment area. The dendritic drainage pattern of the basin reveals moderate slopes while sub-parallel pattern shows high relief and structural control, especially along the 7th order trunk river of the basin. The circularity ratio, elongation ratio and form factor represent that the elongated study area is in the youth stage of basin development. Sub-watersheds belonging to high relief and slope show high bifurcation ratio and drainage density indicating areas under structural control. Whereas variation in values indicate the difference in topography. Stream frequency of all sub-watersheds shows a positive correlation with drainage density due to the hard rock lithological structures which reveals that the surface area has moderate permeability and groundwater potential is meagre. These studies are useful to mark the groundwater potential zone and artificial recharge area and plan for watershed management.

Key words: Morphometric analysis, Suvarnavathi river, ALOS DEM, geographic information system.

Introduction

The quantitative analysis of the drainage system is an important aspect of the characteristics of a watershed (Strahler, 1964). Drainage pattern refers to the spatial relationship among streams or rivers, which may influenc their erosion by inequalities of slopes, soils, rock resistance, structure and geological history of a region. Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Clarke, 1996). This analysis can be achieved through the measurement of linear, areal and relief aspects of the basin and slope contributions (Nag and Chakraborthy, 2003). A similar work has been carried out for six sub-watersheds in the study area, however, the same has not been done for the entire catchment area of the Suvarnavathi river basin (Dinakar et al., 2008). The present case study on drainage basin analysis is performed quantitatively for 13 sub-watersheds namely from SW1 to SW13 of the entire river Suvarnavathi catchment area (Figure 1). The availability of water in the region can be estimated

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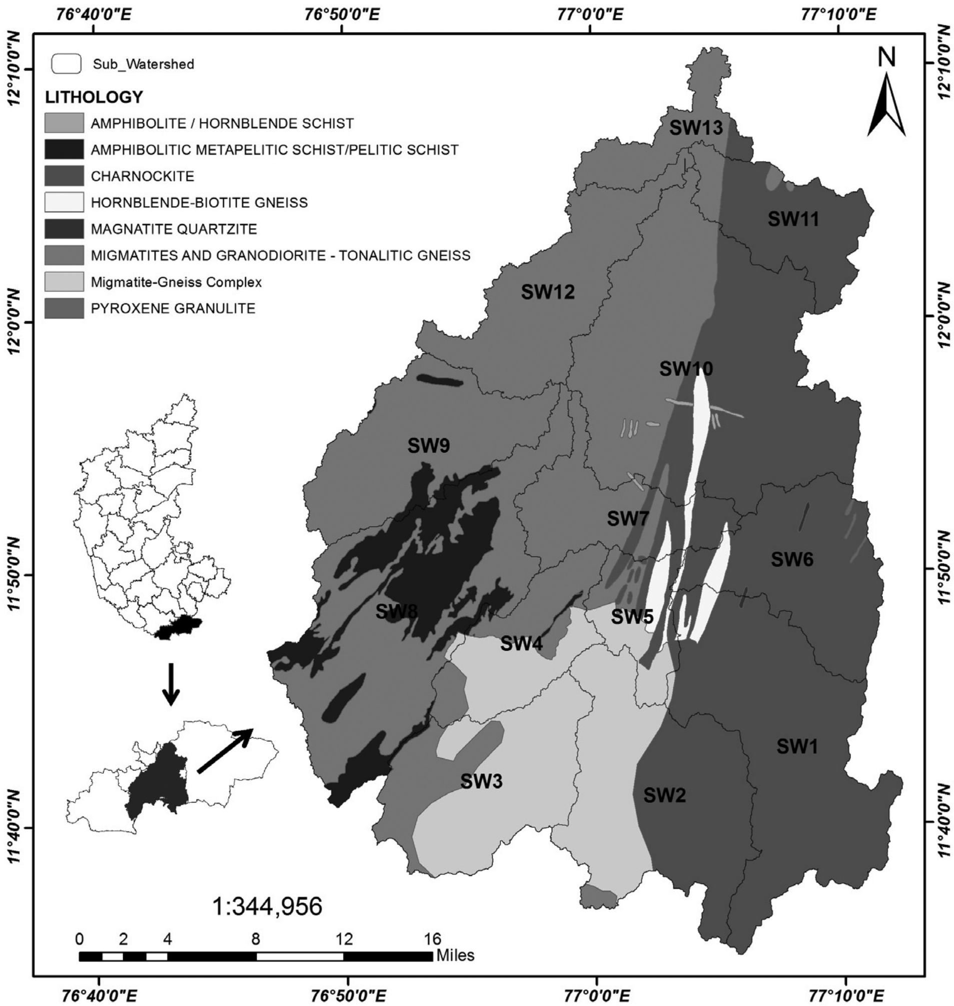

Figure 1: Location map of the Suvarnavathi sub-watersheds with the geological area (*Source*: Geological Survey of India).

through the physical characteristics of different sub-basins. So, the main objective of the present study is to derive the different drainage characteristics of the sub-watersheds of river Suvarnavathi catchment and also understand the relationship among them.

Study Area

The Suvarnavathi river basin lies between 11°34'30" and 12°11'30" N latitudes and 76°48'00" and 77°24'30' E longitudes, which falls in the Karnataka state (two sub-watersheds at the south belongs to Tamilnadu state). It has a catchment area of 1857 sq.km. and is primarily drained by Suvarnavathi and Chikkahole rivers, which are the tributaries of Cauvery. The Suvarnavathi river rises near Gajjalahalli, southeastern portion of Chamarajanagar and finally joins the river Cauvery at Hampapura in Kollegal taluk with a total course length of 88 km in Karnataka. The Chikkahole is a tributary of Suvarnavathy, which rises at the Hasanur ghat range (Nirmala et al., 2019). The study area receives an average annual rainfall of 737mm (2001-2010, DES, Govt of Karnataka). The mean maximum temperature is 34°C and the mean minimum temperature is 16.4°C.

It is a hard rock terrain comprising Peninsular gneiss, widespread formation with Amphibolites, Migmatites and Dolerite dykes. Charnockite which belongs to the Western Ghats is found in south-east part of the study area and limited extent of alluvium restricted mainly to sides of river courses. Structural investigation in the study area; mainly in south-eastern of Biligiri-Rangan Granulites (BRG) has shown at least three deformational events viz., D1, D2, D3. The Kollegal Shear Zone (KSZ) which trends at N10°E to S10°W shows retrograde metamorphic alteration, which demarcates the boundary between the gneisses and BRG (Basavarajappa et al., 2013).

Data Used and Methodology

Automatic extraction methods have been used for assessing the morphometric parameters of a basin by using ALOS DEM image, i.e., extraction of sub-watershed boundaries and stream network of the Suvarnavathi river basin. All the morphometric parameters are calculated by using ArcGIS software i.e., lengths of streams of each order, basin perimeter, drainage area, perimeter and total basin length, and width were calculated by using ArcGIS software. Whereas drainage frequency, drainage density, form factor, shape, circulatory ratio, and elongation ratio, etc., were calculated from these parameters.

Results and Discussion

The area is generally characterised by sub-dendritic to sub-parallel drainage pattern showing a trellis pattern in a few sub-watersheds at the eastern side of the study basin, with general stream flow direction from South to North (Figure 2a). The drainage characteristics of 13 sub-watersheds are determined and summarised in Table 1. The quantitative morphometric analysis provides very consistent information to assess and understand the hydrological behaviour of the rocks and their hydraulic characteristics (Saha and Singh, 2017). Several important linear, areal and relief aspects of Suvarnavathi river sub-watersheds and their hydrological inferences are discussed here in detail.

Linear Aspects

Stream order (u): The primary step in the drainage basin analysis is to determine the stream order, which expresses the hierarchical relationship between stream segments and their connectivity. In the present study, the ranking of the streams has been carried out based on the method proposed by Strahler (1964). The trunk river is of 7^{th} order while the morphometric parameters have been calculated to be 4^{th} order streams (Figure 2a).

Stream Number (Nu): The total number of stream segments present in each order is called the stream number. The maximum value of N1 is 591 in sub-

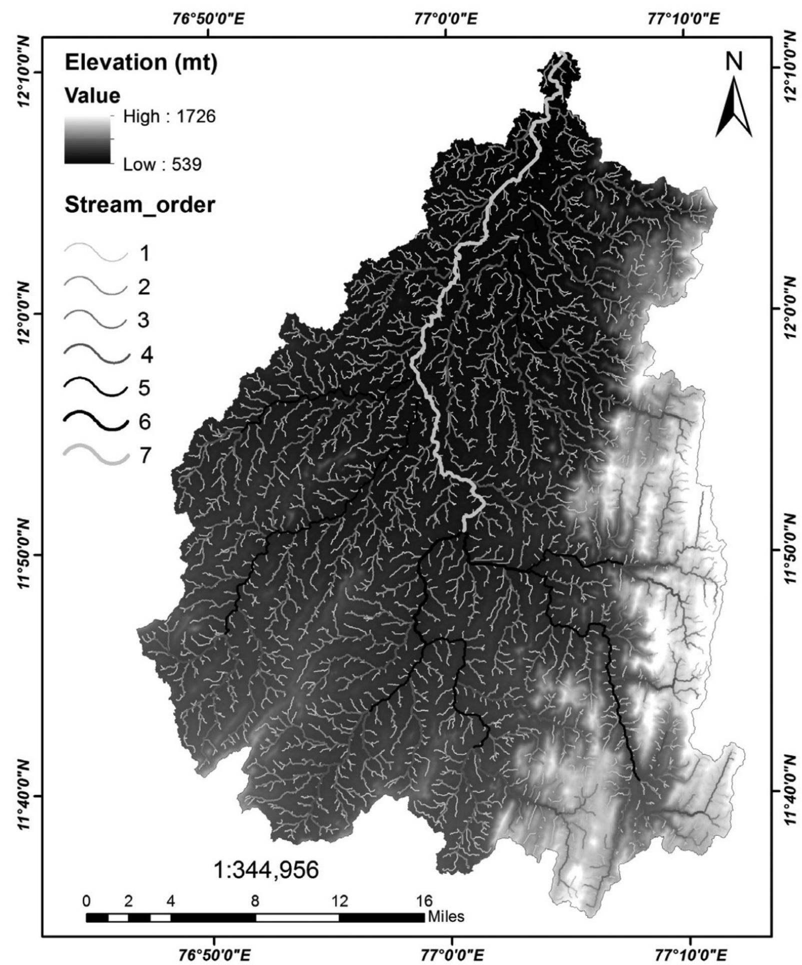

Figure 2(a): Stream network map with elevation.

Table 1: Basic linear parameters of the Suvarnavathi River and its tributaries

Sub-watershed	*Stream Numbers (Nu)*					*Stream Length (Lu)*				
	N1	*N2*	*N3*	*N4*	*Total*	*N1*	*N2*	*N3*	*N4*	*Total*
SW1	381	169	94	41	685	182	85	46	21	334
SW2	309	138	64	64	575	176	70	31	27	304
SW3	244	121	49	54	468	127	69	25	24	245
SW4	150	57	46	15	268	67	35	23	6	131
SW5	83	40	25	2	150	45	26	12	1	84
SW6	206	99	60	21	386	96	47	30	13	186
SW7	147	69	39	11	266	73	43	18	6	140
SW8	458	199	137	48	842	207	112	70	20	409
SW9	223	120	47	18	408	114	72	28	10	224
SW10	591	260	180	106	1137	291	136	95	59	581
SW11	156	64	33	46	299	69	38	14	20	141
SW12	209	97	54	19	379	116	59	36	9	220
SW13	92	42	26	5	165	48	25	11	3	87

watershed SW10 and the minimum is 83 in SW5 (Table 1), which might be due to the surficial area in the same order. The catchments with higher stream orders show fewer Nu values signifying high erosion or soft ground conditions.

Stream length (Lu) and Mean Stream length ratio (RL): The calculated stream length for N1 shows that the SW10 and SW5 have maximum and minimum Lu, respectively. The stream length ratio of L4 and L3 at SW5 is showing very high erosion at the catchment. The mean stream length ratio (RL) varies from 0.78 in SW11 to 0.37 in SW5 while the majority streams are showing an average value of 0.4, which indicates uniform behaviour of the catchments (Strahler, 1964). Mean Bifurcation ratio (Rbm): It is the ratio of the total number of streams or segments of an order to the number of streams of the next higher-order (Schumm, 1956). Rbm value varies from 5.39 in SW5 to 1.7 in SW11 and the mean stream length decreases as the bifurcation ratio increases because of the intensity of erosion in the sub-watershed.

Areal Aspects

Drainage Density (Dd): The region has medium to high drainage density ranging from 1.50 (SW1) to 1.83 (SW12), which could be the result of resistant and impermeable lithology of granodiorites and charnockites (Strahler, 1964). The northern sub-watersheds ranging from SW10 to SW13 have high values of Dd, despite different areal extent, which indicates structural control in the region.

Stream frequency (Fs): The stream frequency of the basin is the number of stream segments of all orders per unit area (Horton, 1945). The SW5 shows 2.94 low values and SW11 shows 3.65 high values. All south-eastern sub-watersheds are showing high values that possess high relief.

Drainage texture (Rt): According to Smith (1950), drainage texture is the total number of stream segments of all orders in a basin per perimeter of the basin. The SW13 shows low texture values of 2.75 and SW10 shows a high value of 9.64. Sub-watersheds that belong to the Western Ghats show high drainage texture because of the high relief aspect, underlying lithology and less infiltration capacity.

Form factor (Ff): It is the ratio of a basin area to the square of the basin length (Horton, 1945). It is also used as a quantitative expression of the basin shape. Lower value factors are observed in all sub-watersheds, which are elongated in shape.

Elongation ratio (Re): Schumn (1956) defined elongated ratio as the ratio of the diameter of the circle of the same area in the basin to the maximum basin length. In the study area, the majority sub-watersheds show values 0.6 to 0.7, which indicate an elongated oval in shape. The lowest value 0.52 in SW8 and SW12 indicates moderate elongation.

Circulatory ratio (Rc): Strahler (1964) demonstrated circularity ratio (Rc) as the ratio of basin area to the area of a circle having the same perimeter of the drainage basin. Rc values vary from 0.17 to 0.44 and the majority of watersheds are showing moderate value except for SW7 and SW13. Lower values of Rc in all sub-watersheds represent the youth stage of basin development where the surface water flow takes comparatively lesser time to reach the basin outlet.

Length of overland flow (Lg): It is the length of water over the ground before it gets concentrated into certain stream channels (Horton, 1945). Table 1 reveals that the length of overland flow values decreases as density increases.

Relief Aspects

Basin relief (H): Basin relief is an important geomorphic factor to understand the erosional and mass movement processes in the basin area. It is defined as the difference between the highest elevation and the lowest elevation within the basin (Hadley and Schumm, 1961). The south-eastern part of structurally controlled sub-watersheds is associated with very high relief value, which indicates steep slope (Figure 2b). Hillslope is dominating processes along with high-velocity runoff and less infiltration potential over the basin area. Low relief sub-watersheds are comparatively flat regions having more dominance of in situ weathering processes (Table 2).

Ruggedness number (HD): Ruggedness number always associated with basin relief and an extreme high value of ruggedness number occurs when both variables are large and slope is steep. Sub-watersheds are associated with very high relief also showing high HD values.

Slope: The slope is an important geomorphic aspect which indicates the degree of inclination of a basin concerning the horizontal surface. By using ALOS DEM data sets, slope maps have been prepared in ArcGIS environment. Observation reveals that variation of

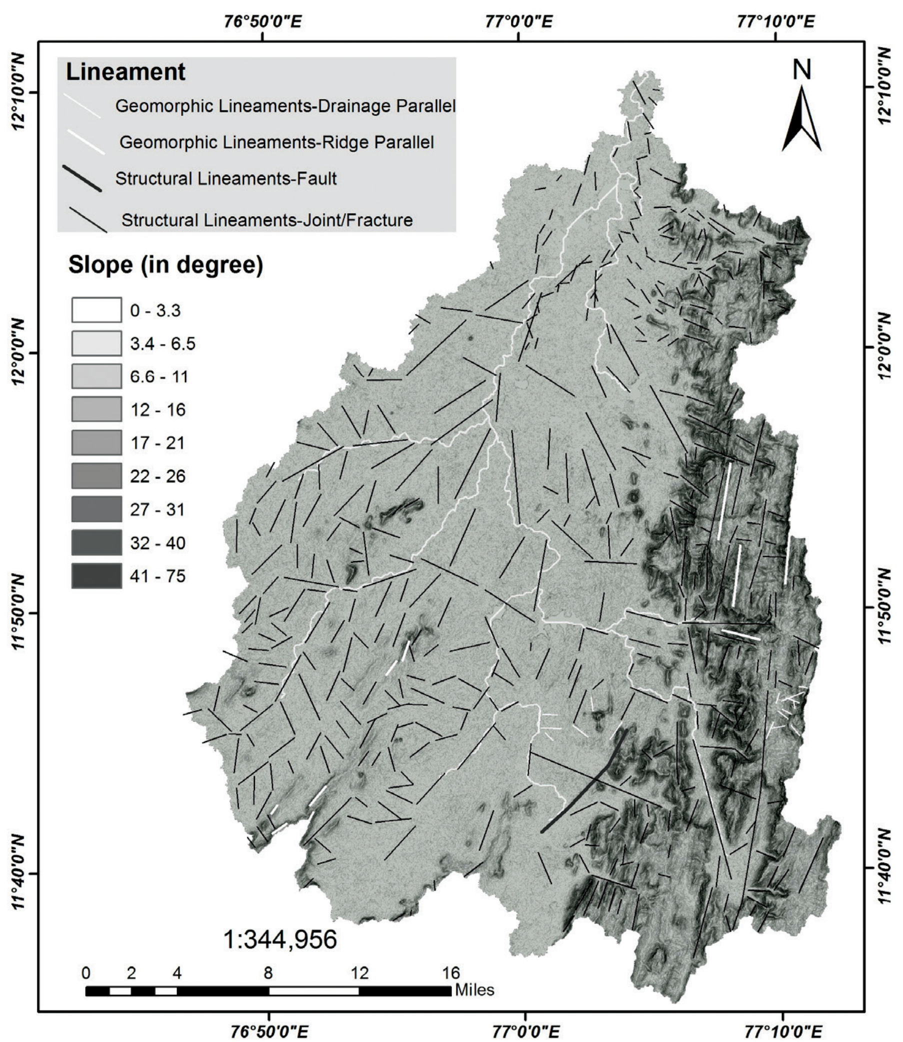

Figure 2(b): Slope with the lineament map.

Table 2: Morphometric indices of Suvarnavathi River Basin

Sub-watershed	*Drainage Density (Dd)*	*Drainage Frequency (Fs)*	*Length of Overland Flow (Lg)*	*Form Factor (Ff)*	*Circularity Ratio (Rc)*	*Elongation Ratio (Re)*	*Texture Ratio (T)*	*Mean Stream Length Ratio*	*Mean Bifurcation Ratio (Rb)*	*Basin Shape (Bs)*	*Total Basin Relief (H)*	*Relief Ratio (Rh)*	*Relative Relief (Rhp)*	*Ruggedness Number (HD)*
SW1	1.50	3.07	1.34	0.30	0.27	0.62	3.74	0.49	2.11	3.32	0.95	0.03	0.93	1.42
SW2	1.62	3.06	1.24	0.33	0.29	0.65	3.43	0.57	1.80	3.03	0.66	0.03	0.73	1.06
SW3	1.71	3.27	1.17	0.38	0.44	0.70	3.81	0.62	1.80	2.60	0.40	0.02	0.63	0.69
SW4	1.52	3.12	1.31	0.27	0.36	0.58	2.73	0.48	2.31	3.73	0.25	0.01	0.46	0.38
SW5	1.65	2.94	1.21	0.35	0.35	0.67	1.93	0.37	5.39	2.84	0.32	0.03	0.73	0.52
SW6	1.51	3.14	1.32	0.47	0.38	0.77	3.22	0.52	2.20	2.13	1.07	0.07	1.67	1.62
SW7	1.67	3.17	1.20	0.30	0.19	0.62	1.96	0.45	2.48	3.34	0.52	0.03	0.69	0.86
SW8	1.59	3.26	1.26	0.21	0.25	0.52	4.02	0.48	2.20	4.77	0.50	0.01	0.44	0.79
SW9	1.71	3.11	1.17	0.29	0.32	0.60	3.10	0.46	2.34	3.48	0.25	0.01	0.35	0.43
SW10	1.82	3.55	1.10	0.45	0.29	0.76	5.01	0.60	1.81	2.23	1.12	0.04	0.95	2.04
SW11	1.72	3.65	1.16	0.32	0.33	0.64	2.79	0.78	1.70	3.09	0.85	0.05	1.51	1.45
SW12	1.83	3.16	1.09	0.20	0.18	0.50	2.30	0.46	2.26	5.04	0.18	0.01	0.20	0.34
SW13	1.81	3.44	1.10	0.22	0.17	0.52	1.53	0.41	3.00	4.64	0.28	0.02	0.46	0.50

slope in study basins ranges from 0° to 75° (Figure 2b). Higher variation of slope at eastern part represents steep scarp with rapid runoff and high erosion vulnerability.

Marking Groundwater Potential Zone 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 properties of the area (Schumm, 1956). Generally, the study area has dendritic drainage pattern with low relief due to more or less homogenous lithology. The hard rock terrain with high relief shows sub parallel (trellis) drainage pattern and high drainage density. Slope is another aspect i.e. infiltration is inversely proportion to slope. In the study area, sub-watersheds belong to gentle slope towards South-North direction showing less drainage density. Low Drainage density with homogenous litho-terrain sub-watersheds is favourable for identification of groundwater potential zones.

Conclusion

The technology of remote sensing and GIS has made geospatial analysis easier. Also by using DEM data, computational studies for the large area can be easily done with high accuracy. The present study describes the morphometric analysis of Suvarnavathi river basin and its 13 sub-watersheds. It has the 4th order of stream in all the sub-watersheds and few have highest 7th order. Drainage network of the basin is dendritic type which specifies the homogeneity in texture, permeability of rock and lack of structural control. The watersheds belong to high relief and steep slope namely SW1, SW2, SW6 and SW10 showing sub-parallel (trellis) pattern along a strike valley because of structural control. Sub-watersheds belong to high relief and the slope shows high bifurcation ratio and drainage density, which indicates low to moderate structural control and variation in values indicates the difference in topography. Medium to high values of Fs and Dd suggest very low permeable lithology with structural control in the basin. Circularity ratio, elongation ratio and form factor denote the oval shape of the basin (0.6-0.7) suggesting youth age with high energy conditions. Relief properties of the drainage basins have shown that the eastern part of the basins has a steep slope, high drainage density and high intensity of erosional mechanism. An overall analysis of the present study indicates young to early-mature stage of drainage development over the study area. These studies are useful to mark the groundwater potential zone and artificial recharge area and can be directly applied for future planning and management of the Suvarnavathi river basin.

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