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Quantitative morphometric characterisation of sub-watersheds in the Amaravati basin using remote sensing and GIS

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Abstract
Drainage-basin morphometry encodes the hydrological, erosional and structural behaviour of a catchment and provides an objective basis for watershed management and groundwater assessment. This study applies an integrated remote-sensing and geographic-information-system (GIS) framework to characterise the morphometry of the Amaravati basin, a tributary catchment of the Cauvery in peninsular India. A digital elevation model was used to delineate the drainage network and to partition the basin into 27 sub-watersheds (SWC1–SWC27). For each sub-watershed, linear (stream order, stream length, stream-length ratio, bifurcation ratio), relief (basin relief, relief ratio, ruggedness number) and areal (drainage density, stream frequency, texture ratio, form factor, circularity ratio, elongation ratio, length of overland flow, constant of channel maintenance) parameters were computed following the standard methods of Horton, Strahler, Schumm and Miller. The network exhibits a predominantly dendritic pattern, indicating relatively homogeneous lithology with limited structural control. Low drainage density and low-to-moderate relief across most sub-watersheds suggest permeable substrate, appreciable infiltration and good groundwater prospects, while elongation- and form-factor values indicate mostly elongated basin shapes associated with attenuated, longer-duration flood peaks. The sub-watershed-scale parameter set provides the quantitative foundation for subsequent prioritisation for soil and water conservation.

Keywords: morphometric analysis; sub-watershed; drainage network; GIS; remote sensing; groundwater; Amaravati basin

1. Introduction

Quantitative geomorphology—the measurement and mathematical analysis of landform dimensions—provides a rigorous description of the surface processes that shape a drainage basin (Strahler, 1964). Because the physiographic attributes of a basin (its size, shape, slope, drainage density, and the length and arrangement of its tributaries) govern the way precipitation is partitioned into infiltration, storage and runoff, morphometric analysis is a standard first step in hydrological investigation, including the assessment and management of groundwater (Horton, 1945; Nag & Chakraborty, 2003).

A watershed is the natural hydrological unit within which all surface runoff converges to a common outlet, and it is therefore the appropriate spatial frame for integrated land- and water-resource planning. Sustainable management within a watershed must reconcile competing demands—drinking water, food production, livelihoods and ecosystem maintenance—against the variability of water in space and time and the added stresses of population growth and climate change. Resolving these demands at an operational scale requires the watershed to be subdivided and each sub-unit characterised individually.

The integration of remote sensing and GIS has transformed morphometric analysis. Digital elevation models (DEMs) permit objective, repeatable extraction of drainage networks and basin parameters that were previously derived by hand from topographic sheets, while GIS enables consistent computation across many sub-basins (Magesh et al., 2013; Rai et al., 2017). Recent studies across Indian river basins have used this approach not only to describe basin morphology but to prioritise sub-watersheds for soil and water conservation, increasingly in combination with statistical methods such as principal component analysis (Chowdari et al., 2023; Aher et al., 2014).

Within this context, the present study characterises the morphometry of the Amaravati basin at sub-watershed scale. Its objectives are: (i) to delineate the drainage network and partition the basin into sub-watersheds from a DEM within a GIS environment; (ii) to compute the standard linear, relief and areal morphometric parameters for each sub-watershed; and (iii) to interpret these parameters in terms of the basin's hydrological behaviour, erosional stage and groundwater potential, thereby establishing the basis for future conservation prioritisation.

2. Study area

The Amaravati River is a major tributary of the Cauvery in southern India, approximately 282 km long. It rises near the Kerala–Tamil Nadu border in the Anaimalai–Palni hills of the Indira Gandhi Wildlife Sanctuary (around 10°21′N, 77°14′E), descends through the Amaravathi Dam and reservoir at Amaravathinagar, and joins the Cauvery near Karur after passing through Udumalaipettai, Dharapuram and Aravakurichi. The basin drains the eastern flank of the southern Western Ghats and the adjoining plains, supporting the fertile agricultural tracts of Dharapuram and Karur (Figure 1).

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Figure 1. Location map supplied with the original manuscript (labelled Telangana/Hyderabad — to be replaced; see note above).

3. Materials and methods

A DEM was used as the primary input. Within a GIS, the DEM was hydrologically conditioned (sink filling), and flow direction and flow accumulation were derived. Stream networks were extracted from the flow-accumulation grid, ordered according to the Strahler hierarchy, and converted to vector features. The basin was then partitioned into sub-watersheds, and the linear, relief and areal morphometric parameters were computed for each (Figure 2).

Watershed size follows standard Indian guidelines (AIS&LUS, 1990; NRSA, 1995), under which a watershed is generally <500 km² and is subdivided into sub-watersheds (30–50 km²), mini-watersheds (10–30 km²) and micro-watersheds (5–10 km²). On this basis the Amaravati basin was divided into 27 sub-watersheds, designated SWC1–SWC27. Linear aspects were analysed following Horton (1945), Strahler (1952) and Schumm (1956); areal aspects following Horton (1945), Miller (1953) and Schumm (1956); and relief aspects following Schumm (1956). The parameters, their formulae and source references are summarised in Table 1.

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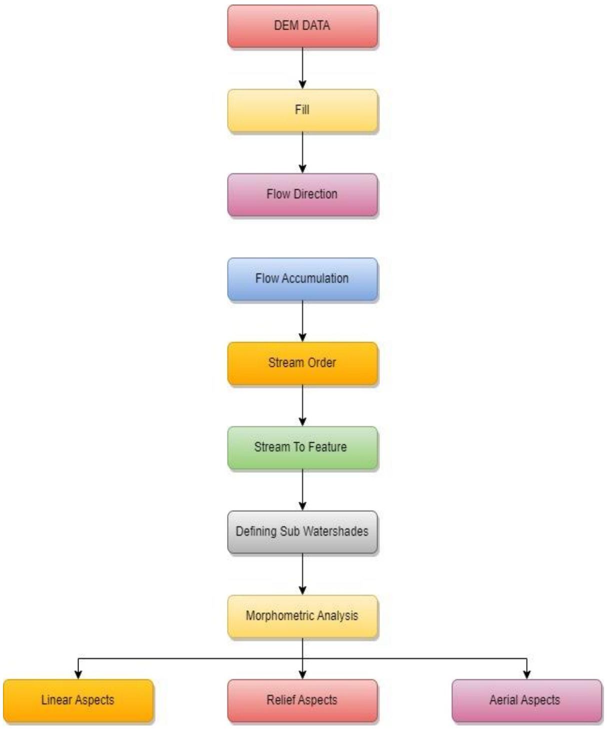

Figure 2. Methodological workflow for DEM-based drainage extraction and morphometric analysis.

Table 1. Morphometric parameters, formulae and references.

Aspect	Parameter	Formula / definition	Reference
Linear	Stream order (U)	Hierarchical ordering of streams	Strahler, 1964
Linear	Stream length (Lu)	Length of stream segments of order u	Horton, 1945
Linear	Mean stream length (Lsm)	Lsm = Lu / Nu	Horton, 1945
Linear	Stream-length ratio (RL)	RL = Lu / Lu−1	Horton, 1945
Linear	Bifurcation ratio (Rb)	Rb = Nu / Nu+1	Schumm, 1956
Relief	Basin relief (Bh)	Bh = Hmax − Hmin	Schumm, 1956
Relief	Relief ratio (Rh)	Rh = Bh / Lb	Schumm, 1956
Relief	Ruggedness number (Rn)	Rn = Bh × Dd	Strahler, 1958
Areal	Drainage density (Dd)	Dd = ΣL / A	Horton, 1932
Areal	Stream frequency (Fs)	Fs = ΣN / A	Horton, 1932
Areal	Texture ratio (T)	T = N1 / P	Horton, 1945
Areal	Form factor (Rf)	Rf = A / Lb^2	Horton, 1932

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Aspect	Parameter	Formula / definition	Reference
Areal	Circularity ratio (Rc)	$Rc = 4\pi A / P^2$	Miller, 1953
Areal	Elongation ratio (Re)	$Re = (2/Lb)\cdot\sqrt{(A/\pi)}$	Schumm, 1956
Areal	Length of overland flow (Lg)	$Lg = 1 / (2\cdot Dd)$	Horton, 1945
Areal	Constant of channel maintenance (C)	$C = 1 / Dd$	Schumm, 1956

4. Results and discussion

The morphometric parameters computed for the 27 sub-watersheds are reported in Tables 2–6 and interpreted below by aspect. Values are discussed as ranges across the sub-watersheds; where individual values fall outside physically plausible bounds, this is flagged for recomputation rather than interpreted.

4.1 Linear aspects

Stream order. Streams were ordered using the Strahler system, in which the smallest unbranched fingertip tributaries are first order, the junction of two first-order streams forms a second-order segment, and so on (Strahler, 1964). Across the basin the network reaches the fourth and, in several sub-watersheds, the fifth order, and displays a dendritic pattern that reflects relatively homogeneous, gently dipping lithology without strong structural control.

Stream length. Stream length reflects the surface-runoff behaviour of the network: longer segments generally indicate gentler gradients, whereas shorter segments are typical of steeper slopes and finer texture. In most sub-watersheds total segment length is greatest for first-order streams and decreases with increasing order (Table 2), consistent with normal network development. Where higher-order segments are anomalously long, structural control (faults, joints or fractures along which channels preferentially incise) may be indicated.

Table 2. Stream length (km) by Strahler order for each sub-watershed.

SWC	1st	2nd	3rd	4th	5th
SWC1	93.13	28.62	12.00	0.04	32.68
SWC2	109.85	63.89	46.21	0.00	0.00
SWC3	19.45	6.18	0.02	11.67	0.00
SWC4	54.77	44.34	0.02	25.53	0.00
SWC5	6.47	0.02	6.96	0.00	0.00
SWC6	74.81	35.68	11.24	0.02	36.66
SWC7	51.82	36.03	13.26	0.03	0.00
SWC8	25.65	37.21	5.35	0.00	0.00
SWC9	10.48	1.99	0.02	10.90	0.00
SWC10	52.46	39.03	0.02	15.87	0.01

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SWC	1st	2nd	3rd	4th	5th
SWC11	66.67	29.93	17.92	0.00	0.00
SWC12	24.52	7.31	0.06	14.29	0.00
SWC13	19.88	1.59	0.04	14.89	0.00
SWC14	117.99	59.96	27.92	4.75	0.00
SWC15	114.09	67.53	30.39	13.86	0.00
SWC16	192.01	86.62	67.23	0.01	0.00
SWC17	252.52	127.10	33.34	49.58	0.00
SWC18	2.33	11.49	0.04	2.10	0.00
SWC19	52.96	33.66	30.10	0.00	0.00
SWC20	12.97	0.02	3.06	0.00	0.00
SWC21	58.47	27.92	17.77	0.00	0.00
SWC22	210.96	94.57	56.79	47.47	0.00
SWC23	216.83	78.37	42.53	0.03	57.84
SWC24	111.35	67.41	24.10	28.83	0.00
SWC25	155.14	74.57	38.71	8.41	0.00
SWC26	69.22	27.22	16.29	14.42	0.00
SWC27	89.73	39.89	35.70	1.78	0.00

Stream-length ratio (RL). The stream-length ratio is the ratio of the mean stream length of one order to that of the next lower order (Horton, 1945) and influences runoff and the basin's erosional stage. Computed values are given in Table 3.

Table 3. Stream-length ratio (RL) by order for each sub-watershed.

SWC	Total	1st	2nd	3rd	4th
SWC1	0.757	0.848	0.448	0.260	0.000
SWC2	5.894	5.648	10.338	2970.064	0.000
SWC3	0.299	0.355	0.139	0.763	0.457
SWC4	9.269	8.460	2889.221	0.003	0.000
SWC5	0.085	0.087	0.000	0.619	0.000
SWC6	1.566	1.444	0.990	0.848	0.563
SWC7	1.483	2.020	0.968	2.479	0.576
SWC8	2.917	2.449	18.676	348.396	0.000
SWC9	0.218	0.200	0.051	0.858	0.687

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SWC	Total	1st	2nd	3rd	4th
SWC10	0.938	0.787	1.304	0.001	0.000
SWC11	2.480	2.719	4.094	296.459	0.000
SWC12	1.269	1.233	4.605	1.463	0.960
SWC13	0.173	0.168	0.026	0.001	3.134
SWC14	0.933	1.034	0.888	0.919	0.343
SWC15	0.653	0.594	0.780	0.452	2166.715
SWC16	0.748	0.760	0.681	2.016	0.000
SWC17	28.981	108.537	11.063	800.017	23.572
SWC18	0.137	0.044	0.341	0.001	0.000
SWC19	7.269	4.082	1370.081	9.840	0.000
SWC20	1.000	0.222	0.001	0.172	0.000
SWC21	0.039	0.277	0.295	0.313	0.000
SWC22	1.036	0.973	1.207	1.335	1460.371
SWC23	1.708	1.947	1.163	1.765	0.001
SWC24	0.837	0.718	0.904	0.622	3.426
SWC25	1.980	2.241	1.869	2.377	0.584
SWC26	0.905	0.771	1.466	0.456	8.111
SWC27	0.757	0.848	0.448	0.260	0.000

Bifurcation ratio (Rb). The bifurcation ratio is the ratio of the number of stream segments of a given order to the number in the next higher order (Schumm, 1956), and is a measure of relief and structural control. Strahler (1957) showed that Rb usually varies within a narrow band (about 3–5) where geological structure does not dominate the drainage pattern. The values computed here are reported in Table 4.

Table 4. Bifurcation ratio (Rb) by order for each sub-watershed.

SWC	Total	1st	2nd	3rd	4th
SWC1	0.714	0.674	0.708	0.190	—
SWC2	3.957	4.600	6.000	21.000	0.000
SWC3	0.511	0.476	0.364	1.000	0.667
SWC4	5.000	7.000	11.000	0.200	—
SWC5	0.115	0.081	0.050	1.667	0.000
SWC6	1.857	1.762	1.667	0.375	1.000
SWC7	1.680	1.615	1.200	4.000	—

SWC	Total	1st	2nd	3rd	4th
SWC8	2.273	3.250	10.000	2.000	0.000
SWC9	0.550	0.250	0.059	1.000	0.385
SWC10	0.488	0.762	1.700	0.100	—
SWC11	1.708	2.100	3.333	5.000	0.000
SWC12	1.043	1.000	1.500	2.000	0.900
SWC13	0.215	0.185	0.061	0.063	2.500
SWC14	1.103	1.102	1.320	1.143	0.444
SWC15	0.664	0.671	0.735	0.368	9.000
SWC16	0.764	0.777	0.708	2.714	0.029
SWC17	21.222	31.333	24.000	7.000	17.500
SWC18	0.209	0.136	0.154	0.250	—
SWC19	6.143	11.000	13.000	2.000	—
SWC20	0.226	0.125	0.100	0.800	—
SWC21	0.169	0.174	0.250	0.208	0.000
SWC22	0.948	0.968	1.212	1.000	13.500
SWC23	2.325	2.262	1.737	2.182	0.182
SWC24	0.883	0.894	0.792	0.647	1.833
SWC25	1.270	1.270	1.200	1.700	0.857
SWC26	1.072	1.057	1.667	0.476	7.000

4.2 Relief aspects

Basin relief (Bh). Basin relief, the elevation difference between the highest and lowest points of a sub-watershed, governs the denudational and erosional behaviour of the terrain and the energy available for runoff (Schumm, 1956). Across the 27 sub-watersheds, basin relief ranges from about 1.6 m to 26.6 m (Table 5), indicating generally low-to-moderate relief and, by extension, moderate runoff energy with appreciable opportunity for infiltration.

Relief ratio (Rh) and ruggedness number (Rn). The relief ratio—total relief divided by basin length (Schumm, 1956)—is dimensionless; higher values denote steeper slopes and faster, more erosive runoff. Computed Rh values range from about 0.07 to 0.64. The ruggedness number, the product of basin relief and drainage density (Strahler, 1958), measures surface irregularity and ranges from about 0.2 to 1.9, again indicating low-to-moderate dissection (Table 5).

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Table 5. Relief parameters and basin dimensions for each sub-watershed.

SWC	Bh (m)	Rh	Rn	Area (km²)	Perim. (km)
SWC1	17.13	0.477	1.8	342.5	153.9
SWC2	3.93	0.071	0.5	481.3	215.3
SWC3	3.47	0.310	0.5	85.7	63.2
SWC4	4.39	0.153	0.4	286.4	188.5
SWC5	2.33	0.305	0.6	28.5	38.8
SWC6	3.51	0.107	0.3	385.0	147.8
SWC7	8.80	0.345	1.1	202.1	110.8
SWC8	1.89	0.081	0.3	154.4	97.4
SWC9	1.91	0.160	0.4	51.9	53.9
SWC10	2.18	0.079	0.2	250.1	133.8
SWC11	5.91	0.220	0.6	255.7	123.4
SWC12	1.60	0.179	0.2	91.7	70.8
SWC13	2.04	0.169	0.3	81.6	73.2
SWC14	7.80	0.241	0.5	467.0	181.5
SWC15	12.96	0.303	1.2	470.8	194.2
SWC16	26.41	0.508	1.9	706.0	224.2
SWC17	26.63	0.641	1.3	862.0	221.2
SWC18	4.19	0.405	1.6	27.7	49.0
SWC19	7.30	0.280	0.9	211.7	155.3
SWC20	1.54	0.230	0.4	25.7	56.8
SWC21	12.60	0.504	1.7	182.1	110.5
SWC22	18.94	0.368	1.2	836.1	245.3
SWC23	19.78	0.392	1.2	819.1	266.0
SWC24	9.58	0.285	0.8	421.5	154.9
SWC25	14.64	0.427	1.0	489.5	188.4
SWC26	7.72	0.331	0.5	327.8	132.5
SWC27	4.46	0.160	0.3	358.8	131.2

4.3 Areal aspects

Drainage density (Dd) and stream frequency (Fs). Drainage density, the total channel length per unit area (Horton, 1932), reflects substrate permeability, vegetation and relief: low values indicate permeable material, good vegetation cover and high infiltration, whereas high values indicate impermeable substrate

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and rapid runoff (Nag & Chakraborty, 2003). Computed Dd values are low (about 0.05–0.37 km/km²), and stream frequency is correspondingly low (about 0.08–0.33 per km²), together implying coarse drainage texture, permeable substrate and favourable groundwater recharge (Table 6).

Shape parameters. Form factor (Rf), circularity ratio (Rc) and elongation ratio (Re) jointly describe basin shape. Form-factor values (about 0.16–1.14, mostly below 0.5) and elongation-ratio values (about 0.22–0.60) indicate that most sub-watersheds are elongated rather than circular. Elongated basins produce lower, longer-duration flood peaks that are easier to manage than the sharp peaks of circular basins. Circularity-ratio values (about 0.10–0.27) likewise denote elongated forms and a late stage of erosional development with limited structural disturbance.

Length of overland flow (Lg) and constant of channel maintenance (C). The length of overland flow—about half the inverse of drainage density (Horton, 1945)—ranges from roughly 0.02 to 0.19 km, while the constant of channel maintenance (the inverse of drainage density; Schumm, 1956) ranges from about 2.7 to 20.8 km² per km. Both are consistent with the low drainage density and indicate that a relatively large area is required to sustain each unit length of channel, again pointing to permeable terrain and good infiltration (Table 6).

Table 6. Areal morphometric parameters for each sub-watershed.

SWC	Dd	Fs	T	Rf	Rc	Lg	C	Re
SWC1	0.105	0.190	0.201	0.265	0.182	0.052	9.530	0.291
SWC2	0.115	0.189	0.214	0.157	0.130	0.058	8.690	0.224
SWC3	0.131	0.268	0.158	0.682	0.270	0.065	7.650	0.466
SWC4	0.100	0.157	0.111	0.349	0.101	0.050	10.000	0.333
SWC5	0.268	0.316	0.077	0.489	0.238	0.134	3.730	0.395
SWC6	0.085	0.203	0.250	0.358	0.221	0.043	11.730	0.337
SWC7	0.126	0.208	0.190	0.310	0.207	0.063	7.920	0.314
SWC8	0.151	0.162	0.133	0.284	0.204	0.076	6.620	0.300
SWC9	0.231	0.212	0.074	0.362	0.224	0.115	4.330	0.339
SWC10	0.111	0.080	0.120	0.326	0.176	0.055	9.030	0.322
SWC11	0.105	0.160	0.170	0.355	0.211	0.052	9.530	0.336
SWC12	0.098	0.262	0.141	1.143	0.230	0.049	10.240	0.603
SWC13	0.147	0.282	0.137	0.563	0.191	0.074	6.780	0.424
SWC14	0.069	0.229	0.297	0.444	0.178	0.035	14.400	0.376
SWC15	0.091	0.206	0.252	0.257	0.157	0.045	11.000	0.286
SWC16	0.074	0.207	0.326	0.261	0.176	0.037	13.570	0.288
SWC17	0.048	0.222	0.425	0.500	0.221	0.024	20.760	0.399

SWC	Dd	Fs	T	Rf	Rc	Lg	C	Re
SWC18	0.373	0.325	0.061	0.259	0.145	0.187	2.680	0.287
SWC19	0.123	0.203	0.142	0.312	0.110	0.062	8.130	0.315
SWC20	0.261	0.272	0.035	0.573	0.100	0.130	3.840	0.427
SWC21	0.137	0.170	0.145	0.291	0.187	0.069	7.280	0.305
SWC22	0.062	0.219	0.375	0.315	0.175	0.031	16.240	0.317
SWC23	0.062	0.236	0.357	0.322	0.145	0.031	16.250	0.320
SWC24	0.080	0.197	0.271	0.373	0.221	0.040	12.550	0.345
SWC25	0.070	0.192	0.249	0.417	0.173	0.035	14.290	0.364
SWC26	0.071	0.226	0.279	0.603	0.235	0.036	14.060	0.438
SWC27	0.078	0.192	0.267	0.464	0.262	0.039	12.900	0.384

5. Conclusion

Integrated remote sensing and GIS provided an accurate and efficient basis for delineating the drainage network of the Amaravati basin and characterising its morphometry across 27 sub-watersheds. The network is predominantly dendritic and broadly homogeneous, with little evidence of strong structural or tectonic control. Low drainage density and stream frequency, together with low-to-moderate relief and ruggedness, indicate permeable substrate, appreciable infiltration and consequently good groundwater prospects across much of the basin, with most sub-watersheds displaying elongated, late-mature forms that favour attenuated flood response. The sub-watershed-scale parameter set developed here is the natural input to a conservation-prioritisation analysis (for example, using a compound-factor or principal-component approach), which is the recommended next step. Before that analysis—and before submission—the flagged bifurcation-ratio and stream-length-ratio computations must be corrected, the in-text and tabulated basin values reconciled, and the study-area location map replaced, so that the geomorphological conclusions rest on internally consistent data.

REFERENCES:

1. Aher, P. D., Adinarayana, J., & Gorantiwar, S. D. (2014). Quantification of morphometric characterization and prioritization for management planning in semi-arid tropics of India: a remote sensing and GIS approach. Journal of Hydrology, 511, 850–860.
2. Chowdari, K. K., Deb Barma, S., Bhat, N., Girisha, R., Gouda, K. C., & Mahesha, A. (2023). Sub-watershed prioritization using morphometric analysis, principal component analysis, hypsometric analysis, land use/land cover analysis, and machine learning approaches in the Peddavagu River Basin, India. Journal of Water and Climate Change, 14(7), 2055–2084.
3. Horton, R. E. (1932). Drainage-basin characteristics. Transactions of the American Geophysical Union, 13(1), 350–361.

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editor@aijmr.com
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CrossRef DOI: 10.62127/aijmr.2026.v03i04.1411

4. Horton, R. E. (1945). Erosional development of streams and their drainage basins: hydrophysical approach to quantitative morphology. Geological Society of America Bulletin, 56(3), 275–370.
5. Magesh, N. S., Jitheshlal, K. V., Chandrasekar, N., & Jini, K. V. (2013). Geographical information system-based morphometric analysis of Bharathapuzha river basin, Kerala, India. Applied Water Science, 3(2), 467–477.
6. Miller, V. C. (1953). A quantitative geomorphic study of drainage basin characteristics in the Clinch Mountain area, Virginia and Tennessee. Technical Report 3, Office of Naval Research, Columbia University.
7. Nag, S. K., & Chakraborty, S. (2003). Influence of rock types and structures in the development of drainage network in hard rock area. Journal of the Indian Society of Remote Sensing, 31(1), 25–35.
8. Rai, P. K., Mohan, K., Mishra, S., Ahmad, A., & Mishra, V. N. (2017). A GIS-based approach in drainage morphometric analysis of Kanhar River Basin, India. Applied Water Science, 7(1), 217–232.
9. Schumm, S. A. (1956). Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. Geological Society of America Bulletin, 67(5), 597–646.
10. Strahler, A. N. (1952). Hypsometric (area-altitude) analysis of erosional topography. Geological Society of America Bulletin, 63(11), 1117–1142.
11. Strahler, A. N. (1957). Quantitative analysis of watershed geomorphology. Transactions of the American Geophysical Union, 38(6), 913–920.
12. Strahler, A. N. (1964). Quantitative geomorphology of drainage basins and channel networks. In V. T. Chow (Ed.), Handbook of Applied Hydrology (pp. 4-39–4-76). McGraw-Hill.