

Quantitative Morphometric Characteristics of the Varthur Catchment Area, Bangalore Urban District, Karnataka, Using Geospatial Techniques

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Abstract

The Varthur Catchment area lies in the southern part of Bangalore Urban District, Karnataka, between 12°48'24.52"N to 12°53'59.85"N and 77°24'59.95"E to 77°30'6.72"E, covering an area of 284 km². Drainage characteristics were extracted from SRTM DEM and IRS P6 LISS III imagery using ArcGIS 10.2.2, and the catchment was delineated into ten sub-watersheds. The catchment is a 5th-order basin with a dendritic drainage pattern. The mean bifurcation ratio is 3.1, total stream length is 327 km, and mean drainage density is 1.31 km/km², indicating moderate permeability. The elongation ratio (0.064) and circularity ratio (0.53) reflect a structurally controlled, elongated basin. Hypsometric analysis yields an integral of 0.46, placing the basin in the mature stage of geomorphic development, with about 54% of the original landmass already eroded. Sub-watershed prioritisation using the composite parameter method identifies SWS-1 and SWS-7 as high-priority zones requiring urgent soil conservation measures and SWS-2, SWS-3, SWS-4, SWS-5, SWS-6, SWS-9, and SWS-10 are classified as moderate priority, indicating moderate infiltration capacity, while SWS-8 shows the lowest erosion risk. The findings provide a baseline for watershed management and sustainable land- and water-resource planning.

Keywords

Morphometric Analysis, Varthur Catchment, Dakshina Pinakini River Basin, GIS, Remote Sensing, Watershed Prioritisation

1. Introduction

Quantitative geomorphology gained scientific momentum following the founda-

tional contributions [1], which demonstrated that stream segment counts and lengths conform the geometric progressions across successive hierarchical orders. These have since been recognised as meaningful indicators of surface hydrological behaviour, encompassing flood characteristics, sediment transport dynamics, and the long-term morphological evolution of drainage basins. Geomorphic attributes of a catchment are widely regarded as sensitive indices of active surface processes.

Remote sensing and GIS-based analytical tools have become indispensable in contemporary morphometric investigations, enabling efficient extraction and spatial analysis of drainage attributes over large basins [2]. The primary objective of the present study is to characterise stream network properties of the Varthur Catchment through systematic measurement of drainage attributes derived from satellite data and Digital Elevation Models (DEMs), with the broader aim of understanding basin hydrodynamics and delineating stages of geomorphic maturity. Geospatial techniques using DEM and GIS have enabled quantitative evaluation of drainage characteristics, supporting watershed prioritisation and sustainable resource planning [3] [4].

2. Study Area

The Varthur Catchment area occupies between latitudes 12°48'24.52"N to 12°53'59.85"N and longitudes 77°24'59.95"E to 77°30'6.72"E, encompassing a geographic extent of 284 km². The mean annual precipitation is 900 mm.

Geologically, the area is underlain predominantly by crystalline basement lithologies, comprising gneissic complexes and granitic intrusions dissected by mafic dykes [5]. Lateritic weathering profiles have developed along the city's eastern fringes. The catchment subsurface hydrogeological conditions are largely governed by weathering, structural discontinuities, topographic morphology, and seasonal recharge inputs. Groundwater resources in the Bengaluru metropolitan area are considered significantly over-exploited, with marked deterioration in water quality. Studies highlight strong dependence on monsoon rainfall and geological heterogeneity influencing morphometric responses [5] [6].

3. Methodology

Thematic outputs were generated using IRS P6 LISS III multispectral satellite imagery. Topographic base layers were compiled from Survey of India (SOI) maps at scales of 1:240,000 and 1:50,000. Elevation data were sourced from the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) at 90 m spatial resolution, which served as the primary input for producing catchment derivatives, including slope maps and automated drainage delineation. A standard False Colour Composite (FCC) was generated by assigning Bands 3, 2, and 1 to the red, green, and blue display channels, thereby enhancing the visibility of geomorphic features, vegetation, and land cover characteristics. All spatial data processing was executed within the ArcGIS 10.2.2 environment [4].

The drainage-extraction workflow proceeded in five sequential steps. 1) The

SRTM tile covering the study area was mosaicked and re-projected to WGS 1984/UTM Zone 43N. 2) Spurious depressions were eliminated using the ArcGIS “Fill” hydrology tool to produce a hydrologically conditioned DEM. 3) The D8 single-flow-direction algorithm was applied to the filled DEM to generate a flow-direction raster. 4) A flow-accumulation raster was derived by tallying the number of upstream contributing cells for every grid cell. 5) Streams were initiated where the flow-accumulation value exceeded a threshold of 500 cells (equivalent to approximately 4.05 km² of contributing area), producing a raster channel network that was subsequently converted to a vector polyline layer for order assignment and length measurement.

Sub-watershed delineation was accomplished by placing pour points at ten strategic junctions along the main channel and applying the ArcGIS “Watershed” tool to each pour point using the conditioned flow-direction raster. The resulting ten sub-watershed (SWs) polygons were used as spatial units for all subsequent parameter calculations. Within each SWs, stream orders were assigned following Strahler’s (1964) hierarchical method [7]: first-order channels are defined as unbranched headwater streams; when two streams of order u meet, they produce a stream of order $u + 1$. This procedure was applied consistently to the full drainage network raster before polygon-based extraction, ensuring that stream-order assignments are independent of sub-watershed boundaries.

Limitations: The use of 90 m SRTM data introduces several constraints that should be considered when interpreting the derived morphometric indices. First, small ephemeral channels narrower than approximately one to two grid cells may not be detected, leading to underestimation of first-order stream counts and drainage density in finely dissected sub-catchments. Second, in the rapidly urbanising Varthur area, the built environment has substantially modified natural drainage paths through road embankments, culverts, stormwater drains, and channelised lake outflows; the SRTM surface represents the topographic reality at the time of acquisition (February 2000) and may not accurately reflect current hydraulic connectivity. Third, urban building masses can produce localised DEM artefacts that distort flow-direction computations.

4. Morphometric Analysis

Watershed geometry was systematically characterised by computing parameters spanning three analytical dimensions: 1) linear aspects, 2) areal aspects, and 3) relief aspects. Primary morphometric inputs, including stream segment counts, channel lengths, catchment area, basin perimeter, main channel length, and sub-basin dimensions, were extracted from the delineated drainage network. Derivative indices such as drainage density, stream frequency, shape descriptors, elongation ratio, and circularity ratio were subsequently computed from these base parameters [1] [8] [9].

4.1. Linear Aspects

Linear morphometric characteristics of the drainage network encompass stream

ordering, segment enumeration, bifurcation ratios, channel lengths, length ratios, and stream frequency parameters.

4.1.1. Stream Order (u)

Stream hierarchy was assigned following the classification scheme [7], applied to drainage networks digitised from topographic maps and satellite imagery. Five hierarchical orders were identified across the study catchment. As is characteristic of dendritic system, first-order channels dominate both segment count and cumulative length, with both metrics diminishing progressively at higher orders. This systematic decline likely reflects the influence of elevated source elevations and spatial variations in underlying lithology.

4.1.2. Stream Number (Nu)

Stream ordering constitutes the initial phase of drainage network analysis, providing a quantitative measure of branching hierarchy across each of the ten delineated sub-watersheds (SWs). Individual stream segments are classified hierarchically, with each assigned an order corresponding to its position within the network. Application of Strahler's (1964) [7] hierarchical method yielded five distinct stream orders across the study area, with first-order tributaries recording the highest segment frequencies. Sub-watershed stream orders consistently span the first through fifth hierarchical levels, and first-order channels exhibit the greatest channel lengths, which decrease systematically at successively higher orders, a pattern reflective of high-elevation headwater origins coupled with lithological variability.

4.1.3. Bifurcation Ratio (Br)

The bifurcation ratio expresses the numerical relationship between streams of a given order and those of the next higher order. This dimensionless index captures the degree of network branching complexity and delineates genetically significant segments within a fluvial system. It serves as a proxy for relief intensity and the degree of terrain dissection within the catchment [1]. Undisturbed drainage networks, unaffected by tectonic interference, characteristically display low bifurcation values [10], whereas elevated ratios indicate structural control and diminished permeability, resulting in enhanced surface runoff [4]. Across the study catchment, bifurcation ratio values span 1 to 8, with an overall mean of 3.1, consistent with the natural range of 3 to 5.

4.1.4. Stream Length (Lu)

Stream length of each order represents the aggregate length of all individual channel segments classified under that order (Equation (1)):

$$Lu = L1 + L2 + \dots + Ln \quad (1)$$

where Lu is the total stream length of a given order, and L1 through Ln denote the lengths of individual segments. Channel lengths across the study area are 192 km, 67 km, 46 km, 13 km, and 9 km of 1, 2, 3, 4 and 5 orders, yielding a total network length of 327 km [6]. Variations in stream length ratios indicate geomorphic ma-

turity and influence flow velocity [6]. The observed decrease in length with increasing order is consistent with Horton's stream length law, reflecting high-elevation headwater conditions, lithological diversity, and moderate terrain gradients [11].

4.1.5. Mean Stream Length (L_u)

Mean stream length, derived by dividing the total channel length of each order by the corresponding segment count, furnishes a dimensionless characteristic representing the typical scale of network components and their associated contributing areas (Equation (2)):

$$L_u = L_u / N_u \quad (2)$$

where N_u denotes the number of stream segments of order u . Computed values for each sub-watershed are presented in Table 1.

Table 1. Linear morphometric parameters of the Varthur area.

SWS	Area (km ²)	P (km)	Pr	Lb (km)	Total Streams	Total Length (km)	Sf	Dd (km/km ²)	Br (Mean)
SWS-1	45.2	34.24	1.32	8.55	36	39.9	0.80	0.88	2.08
SWS-2	23.81	23.46	1.01	9.28	37	37.53	1.55	1.60	2.42
SWS-3	10.22	18.86	0.54	7.39	15	11.49	1.47	1.40	2.13
SWS-4	32.98	27.28	1.21	9.14	57	44.51	1.70	1.44	3.13
SWS-5	22.53	24.47	0.92	8.83	43	25.01	1.91	1.11	2.50
SWS-6	34.22	27.04	1.27	9.08	56	51.29	1.64	1.56	3.07
SWS-7	49.04	44.33	1.11	12.43	37	25.74	0.77	0.58	3.31
SWS-8	7.97	16.39	0.49	3.06	15	13.83	1.88	1.74	0.92
SWS-9	37.37	28.98	1.29	9.73	66	52.15	1.77	1.45	3.11
SWS-10	21.03	22.32	0.94	5.03	37	28.66	1.76	1.36	2.75

4.1.6. Stream Length Ratio (L_r)

The stream length ratio expresses the relationship between the mean channel length of a given order and that of the immediately preceding higher order (Equation (3)):

$$L_r = L_u / L_{u-1} \quad (3)$$

where L_u is the mean channel length of order u , and L_{u-1} is the mean length of the next lower order. This ratio tends toward constancy across successive orders within a single watershed and increases exponentially with ascending order. Observed variability in L_r values across the network reflects local changes in gradient and topographic configuration. Within the study area, mean stream length ratios range from a maximum of 6.34 to a minimum of 0.44, recorded in SWS-9. Lower-order streams exhibit parallel drainage alignments attributable to tectonic structural controls, while the predominantly hilly terrain, intense monsoon precipitation, and steep scarps constrain fifth-order channel development to low-relief slope

segments.

4.1.7. Stream Frequency (S_f)

Stream frequency quantifies the total number of channel segments across all hierarchical orders per unit catchment area [1] (Equation (4)):

$$S_f = N_u/A \quad (4)$$

where N is the total segment count and A is the watershed area. Computed S_f values across sub-watersheds range from 0.77 to 1.91 per km^2 . Elevated stream frequency values are associated with steeper terrain and higher surface runoff potential. Fine drainage texture characterised by high frequency implies reduced subsurface permeability and greater overland flow generation, whereas coarse texture promotes infiltration and aquifer recharge [3]. The study area exhibits conditions favourable for moderate infiltration and groundwater replenishment.

4.2. Areal Aspects

The areal morphometric dimension encompasses basin area, perimeter, drainage density, drainage texture, elongation ratio, circularity ratio, form factor, and overland flow. These geometrically derived properties are fundamentally conditioned by lithological character, structural fabric, and topographic relief.

4.2.1. Area (A_u) and Perimeter (P)

Catchment area and perimeter were measured using ArcGIS polygon computation functions and expressed in km^2 and km , respectively. The total perimeter of the Varthur Catchment measures 267.37 km , while the delineated basin area is 284 km^2 . The Relative Perimeter (R_p), computed as (Equation (5)):

$$R_p = A/P \quad (5)$$

yielded a value of 1.06 km , indicative of an elongated irregular basin configuration. This morphology promotes gradual runoff concentration and, correspondingly, enhanced potential for infiltration and groundwater storage.

4.2.2. Drainage Pattern

Drainage patterns describe the preferred spatial orientation and organisation of channel networks across a landscape, reflecting the combined influence of initial topographic gradients, bedrock lithology, and prevailing climatic conditions [12]. The Varthur Catchment exhibits a diverse suite of drainage morphologies, with dendritic, parallel, and sub-parallel configurations observed across its spatial extent (Figure 1).

4.2.3. Drainage Density (D_d)

Drainage density, originally defined [1] [13] as the total channel length per unit catchment area, serves as a key indicator of terrain dissection, runoff potential, and subsurface permeability (Equation (6)):

$$D_d = L_u/A \quad (6)$$

where L_u is the total stream network length and A is the catchment area. High D_d

values characterise intensely dissected basins with rapid hydrological responses to precipitation events [3], whereas low values typify poorly drained systems with sluggish runoff generation. This is responsive to climatic regime, vegetation density, soil and rock permeability, topographic relief, and geomorphic history. Drainage density values across the sub-watersheds of the Varthur Catchment range from 0.58 to 1.735 km/km². Except SWs, the remaining 7 SWs show higher Dd values, indicating high surface runoff.

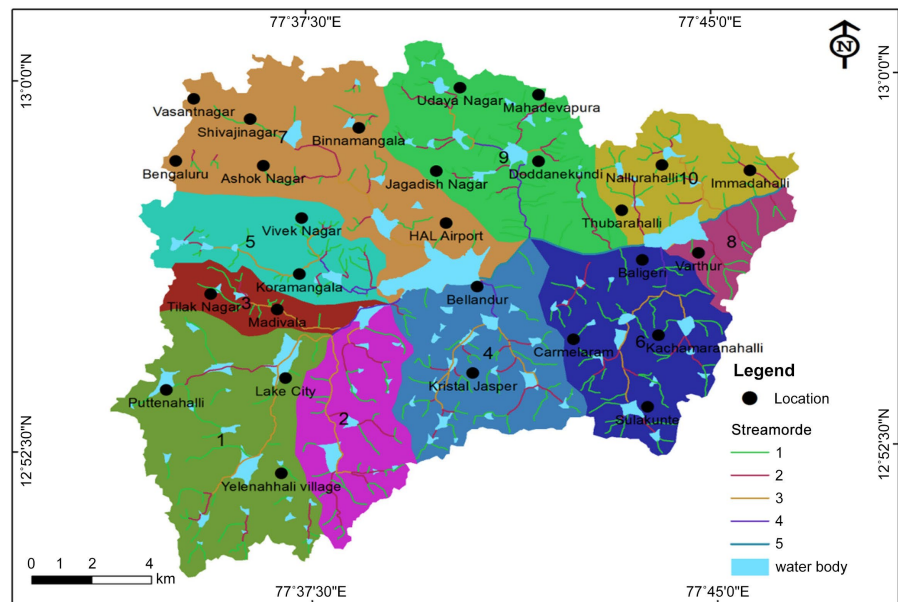


Figure 1. Drainage map of 10 sub-watersheds of the Varthur Catchment.

4.2.4. Drainage Texture (Dt)

Drainage texture expresses the ratio of total stream segments across all orders to the catchment perimeter [1] (Equation (7)):

$$Dt = Dd/S_f \quad (7)$$

Smith (1950) [14] proposed a five-class categorisation of drainage texture: very coarse (<2), coarse (2 - 4), moderate (4 - 6), fine (6 - 8), and very fine (>8). Within the study catchment, drainage texture values range from 0.9 to 1.72, consistently placing the sub-watersheds within the very coarse class. This classification reflects the presence of impermeable crystalline basement lithology, which promotes more numerous channel segments relative to permeable substrates [6]. Drainage texture serves as an indicator of subsurface infiltration capacity.

4.2.5. Elongation Ratio (Er)

The elongation ratio, as conceptualised by Schumm (1956) [8], expresses the diameter of a circle of equivalent area to the basin relative to the basin's greatest axial length (Equation (8)):

$$E_r = (2/L_b) \times \sqrt{(A/\pi)} \quad (8)$$

where L_b is the sub-watershed length and A is its area. Circular basins generate

more rapid and concentrated runoff relative to elongated counterparts [4]. Computed elongation ratio values across the study catchment range from 0.041 to 0.41, indicating a predominantly highly elongated configuration.

4.2.6. Circularity Ratio (C_r)

The circularity ratio quantifies the degree to which a basin approximates a circular shape by comparing its area to that of a circle possessing an equivalent perimeter (Equation (9)):

$$C_r = 12.57 \times A/P^2 \quad (9)$$

Sub-watershed circularity ratios range from 0.314 to 0.588; those with values at or above 0.5 reflect moderate circularity, associated with intermediate runoff and infiltration characteristics.

4.2.7. Form Factor (F_f)

The form factor, introduced [1], represents the ratio of catchment area to the square of the basin length (Equation (10)):

$$F_f = A/Lb^2 \quad (10)$$

F_f ranges between 0 for highly elongated basins and 1.0 for perfectly circular configurations. Study area sub-watershed values span 0.18 to 0.851, suggesting moderate elongation overall. Sub-watersheds with high F_f produce brief but intense discharge peaks, while those with lower values (e.g., SWS-5 at 0.289) generate more sustained, attenuated peak flows [3] [15]. The complementary shape factor (S_f), ranging from 1.17 to 5.34, further underscores basin morphological irregularity, which is conducive to recharge augmentation and flood attenuation in elongated systems.

4.2.8. Length of Overland Flow (LoF)

Overland flow length characterises the average distance traversed by runoff across the land surface prior to channelisation, approximated as half the reciprocal of drainage density [1] (Equation (11)):

$$LoF = A/(2 \times Lu) \quad (11)$$

Computed LoF values across sub-watersheds range from 0.29 to 0.86, suggesting the dominance of channelised erosion over diffuse sheet erosion processes within the catchment.

The areal morphometric parameters were computed for each of the ten delineated sub-watersheds (SWS-1 through SWS-10) of the Varthur Catchment (Table 2). The parameters presented include mean bifurcation ratio (R_{bm}), drainage density (D_d , km/km²), elongation ratio (R_e), circularity ratio (R_c), drainage texture (D_t), form factor (F_f), shape factor (S_f), and length of overland flow (L_g). Drainage density values range from 0.580 (SWS-7) to 1.735 km/km² (SWS-8), reflecting variability in subsurface permeability and terrain dissection across the catchment. Elongation ratios (0.041 - 0.41) and circularity ratios (0.314 - 0.588) consistently indicate elongated, structurally influenced basin morphologies. Drainage texture values (0.58 - 1.46) classify all sub-watersheds within the very coarse category, consistent

with the impermeable crystalline basement lithology of the region.

Table 2. Areal morphometric parameters of the Varthur Catchment.

SWS	Brm	Dd	E _r	C _r	Dt	Ff	Sf	LoF
SWS-1	2.08	0.883	0.062	0.485	1.11	0.618	1.62	0.57
SWS-2	2.42	1.597	0.078	0.544	1.03	0.276	3.62	0.31
SWS-3	2.13	1.403	0.150	0.361	0.96	0.187	5.34	0.36
SWS-4	3.13	1.436	0.068	0.557	1.00	0.395	2.53	0.35
SWS-5	2.50	1.110	0.085	0.473	0.58	0.289	3.46	0.45
SWS-6	3.07	1.557	0.067	0.588	0.90	0.415	2.41	0.32
SWS-7	3.31	0.580	0.041	0.314	0.75	0.317	3.15	0.86
SWS-8	0.92	1.735	0.410	0.373	1.46	0.851	1.17	0.29
SWS-9	3.11	1.451	0.060	0.559	0.93	0.395	2.53	0.34
SWS-10	2.75	1.363	0.154	0.531	0.99	0.831	1.20	0.37

4.3. Relief Aspects

While linear and areal parameters characterise the two-dimensional planimetric form of a drainage basin, relief parameters introduce the vertical dimension, capturing the elevation structure and erosional intensity of the landscape.

4.3.1. Relative Relief (RR)

Relative relief denotes the vertical distance separating the highest and lowest elevation points within a watershed [16] [17] (Equation (12)):

$$RR = M - m \quad (12)$$

Sub-watershed relative relief values range from 42 m (SWS-7) to 81 m (SWS-1), indicating low to moderate terrain variability consistent with a weathered gneissic basement.

4.3.2. Relief Ratio (Rr)

Relief ratio, as formalised [8], is defined as the quotient of the maximum basin relief and the horizontal distance measured along the longest axis parallel to the principal drainage line (Equation (13)):

$$Rr = H/Lb \quad (13)$$

The study catchment records an overall Rr of 0.082, indicative of moderate relief with gently inclined slopes.

4.3.3. Ruggedness Number (Rn)

The ruggedness number integrates basin relief with drainage density to provide a composite measure of terrain structural complexity (Equation (14)):

$$Rn = Dd \times H/1000 \quad (14)$$

Ruggedness values across sub-watersheds range from 0.045 (SWS-7) to 0.104 (SWS-2), reflecting predominantly gentle topography with limited erosion suscep-

tibility [6] [18].

4.3.4. Slope Analysis

Slope was characterised as the rate of elevation change over a horizontal distance, expressed in degrees and derived from the SRTM DEM using spatial analyst tools within ArcGIS. Varthur Catchment is characterised by gentle to moderate gradients across the majority of its extent, with steeper slopes confined to higher-elevation zones above approximately 900 - 920 m. The broader low-relief terrain below 880 - 900 m is suited to moderate surface runoff generation, reduced erosion potential, and agricultural activities.

Table 3. Relief parameters of the Varthur Catchment area.

SWS	RR (m)	Rr	Rn	MRn	Di	Mean Slope	Slope Ruggedness
SWS-1	81	0.009	0.072	0.012	0.084	1.679	1.482
SWS-2	65	0.007	0.104	0.013	0.069	1.526	2.437
SWS-3	60	0.008	0.084	0.019	0.064	1.495	2.097
SWS-4	61	0.007	0.088	0.011	0.066	1.405	2.017
SWS-5	55	0.006	0.061	0.012	0.059	1.417	1.573
SWS-6	58	0.006	0.090	0.010	0.063	1.361	2.120
SWS-7	77	0.006	0.045	0.011	0.082	1.401	0.812
SWS-8	42	0.014	0.073	0.015	0.047	1.175	2.038
SWS-9	60	0.006	0.087	0.010	0.065	1.396	2.025
SWS-10	63	0.013	0.086	0.014	0.069	1.265	1.725

Table 3 presents the relief morphometric parameters for each sub-watershed, encompassing maximum elevation (M, m amsl), minimum elevation (m, m amsl), relative relief (RR, m), relief ratio (Rr), ruggedness number (Rn), modified ruggedness number (MRn), dissection index (Di), mean slope (degrees), and slope ruggedness. Relative relief ranges from 42 m (SWS-8) to 81 m (SWS-1), indicating low-to-moderate terrain variability consistent with a mature, weathered gneissic landscape. The overall relief ratio of 0.082 confirms gentle-to-moderate slope inclinations across the catchment. Ruggedness numbers (0.045 - 0.104) reflect predominantly gentle topography with limited erosion susceptibility, while mean slope values (1.175° - 1.679°) highlight the dominance of low-gradient terrain, particularly in the southern and south-eastern pediplain zones.

4.4. Hypsometric Analysis (Hi)

Hypsometric analysis evaluates the distribution of watershed area across elevation, providing insights into the stage of landscape development, erosional status, tectonic history, and geomorphic evolution. A concave hypsometric curve with an integral (Hi) of 0.46 places the Varthur Catchment in the mature stage of geomorphic development, approaching the monadnock phase. The hypsometric integral of 46%

implies that approximately 54% of the original landmass volume has been removed through erosive processes (**Table 4, Figure 2**). These values are consistent and derived from the area-elevation data tabulated in **Table 4**.

Table 4. Hypsometric integrals of the study area.

Sl. No.	Area (km ²)	Elevation (m)	h	a	a/A	h/H	Hi
1	0.69	852	8	286.20	1.00	0.08	0.46
2	11.66	861	16	285.51	1.00	0.17	
3	25.34	870	24	273.85	0.96	0.25	
4	42.97	879	32	248.50	0.87	0.33	
5	55.72	888	40	205.53	0.72	0.42	
6	57.87	897	48	149.81	0.52	0.50	
7	45.81	906	56	91.94	0.32	0.58	
8	26.40	915	64	46.13	0.16	0.67	
9	12.82	924	72	19.73	0.07	0.75	
10	5.77	933	80	6.91	0.02	0.83	
11	1.08	942	88	1.13	0.00	0.92	
12	0.05	951	96	0.05	0.00	1.00	

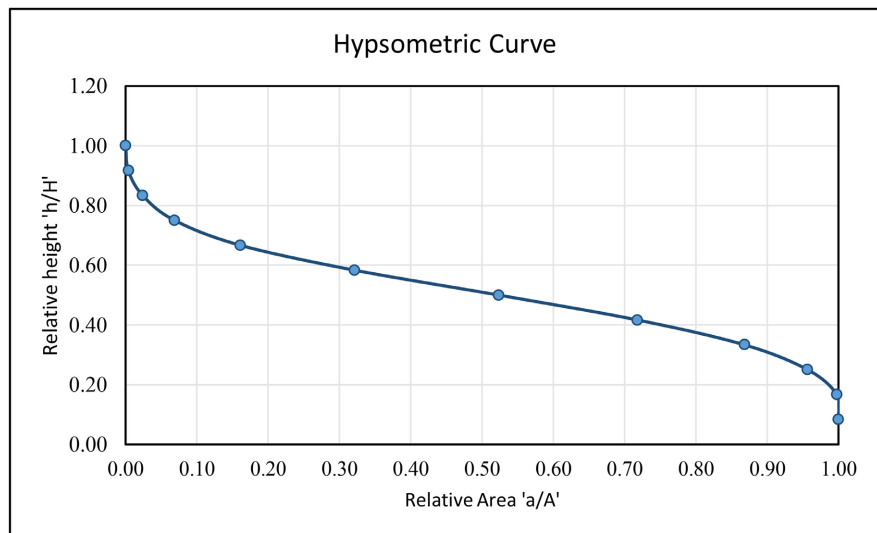


Figure 2. Hypsometric curve of the Varthur Catchment area

5. Sub-Watershed Prioritisation

The Varthur Catchment area has been delineated into ten sub-watersheds were ranked and prioritised using the composite parameter (Cp) method, which integrates eleven morphometric indices: Stream Frequency (Sf), Drainage Density (Dd), Drainage Texture (Dt), Elongation Ratio (Fr), Circularity Ratio (Cr), Form Factor (Ff), Overland Flow Length (LoF), Relief Ratio (Rr), Ruggedness Number (Rn), Dissection Index (Di), and Mean Slope. For each index, all ten SWs are ranked from

1 to 10. Indices that are positively correlated with erosion risk S_f , D_d , D_t , R_r , R_n , D_i , and Mean Slope are ranked such that the SWS with the highest value receives Rank 1 (highest erosion priority). Conversely, shape indices that are inversely correlated with erosion risk E_r , R_c , F_f , and LoF are ranked such that the SWs with the lowest value (most circular or compact) receive Rank 1. The C_p for each SW is the arithmetic mean of its 11 individual index ranks. A lower C_p therefore indicates greater overall erosion susceptibility and higher management priority. Sub-watersheds were subsequently grouped into three priority categories: High ($C_p < 8$), Moderate ($C_p 8 - 10$), and Low ($C_p \geq 10$) following [2]. C_p values range from 6.00 (SWS-7) to 10.36 (SWS-8) (**Table 5**).

Table 5. Sub-watershed prioritisation based on morphometric parameters.

SWS	S_f	D_d	D_t	E_r	R_c	F_f	LoF	R_r	R_n	D_i	Mean Slope	C_p	Priority
SWS-1	0.80	0.88	1.11	0.06	0.49	0.62	0.57	0.01	0.07	0.08	1.68	7.86	High
SWS-2	1.55	1.60	1.03	0.08	0.54	0.28	0.31	0.01	0.10	0.07	1.53	9.55	Moderate
SWS-3	1.47	1.40	0.96	0.15	0.36	0.19	0.36	0.01	0.08	0.06	1.49	8.65	Moderate
SWS-4	1.70	1.44	1.00	0.07	0.56	0.40	0.35	0.01	0.09	0.07	1.40	9.10	Moderate
SWS-5	1.91	1.11	0.58	0.09	0.47	0.29	0.45	0.01	0.06	0.06	1.42	8.02	Moderate
SWS-6	1.64	1.56	0.90	0.07	0.59	0.42	0.32	0.01	0.09	0.06	1.36	9.13	Moderate
SWS-7	0.77	0.58	0.75	0.04	0.31	0.32	0.86	0.01	0.05	0.08	1.40	6.00	High
SWS-8	1.88	1.74	1.46	0.41	0.37	0.85	0.29	0.01	0.07	0.05	1.17	10.36	Low
SWS-9	1.77	1.45	0.93	0.06	0.56	0.40	0.34	0.01	0.09	0.07	1.40	9.09	Moderate
SWS-10	1.76	1.36	0.99	0.15	0.53	0.83	0.37	0.01	0.09	0.07	1.27	9.17	Moderate

5.1. High Priority

Sub-watersheds SWS-1 ($C_p = 7.86$) and SWS-7 ($C_p = 6.00$) fall within the high-priority category, characterised by steep topography, elevated drainage density, high stream frequency, low form factor, and low elongation ratio. These conditions denote severe erosion susceptibility, warranting immediate implementation of mechanical soil conservation interventions, including gully stabilisation structures and grass waterways to curtail topsoil loss to improve infiltration capacity.

5.2. Moderate Priority

Seven sub-watersheds SWS-2, SWS-3, SWS-4, SWS-5, SWS-6, SWS-9, and SWS-10 are classified as moderate priority ($C_p 8.02 - 9.55$). These exhibit intermediate slope gradients, moderate values of drainage density, stream frequency, and drainage texture, and moderate-to-high form factor, circularity, and elongation ratios, indicating moderate infiltration capacity.

5.3. Low Priority

SWS-8 ($C_p = 10.36$) attains low-priority status, characterised by subdued slopes, the

lowest relative relief (42 m), and the highest form factor (0.851), indicating a compact, low-gradient sub-catchment. Although it possesses the highest drainage density (1.74 km/km²), this is offset by the very gentle terrain, resulting in the lowest overall erosion risk among all sub-watersheds, which leads to high runoff and low infiltration.

6. Conclusions

The present investigation establishes a comprehensive baseline morphometric dataset for the Varthur Catchment through systematic analysis of linear, areal, and relief parameters derived from satellite imagery and GIS-based processing. Principal conclusions are drawn as follows:

- The drainage network exhibits five hierarchical orders consistent with Strahler (1964) [7]. Stream segment counts and cumulative lengths diminish systematically with ascending order.
- The dominant drainage is dendritic, with secondary parallel and sub-parallel patterns reflecting underlying structural and lithological heterogeneity.
- Mean bifurcation ratio of 3.1 falls within the natural range of 3 - 5, though certain sub-watersheds exceed this threshold, indicating localised geological control.
- Total stream length is 327 km. Progressive channel length reduction with increasing order is consistent with Horton's stream length law [1].
- The delineated basin encompasses 284 km². Drainage density averages 1.31 km/km², indicative of moderate permeability and intermediate drainage development.
- A catchment elongation ratio of 0.064 and circularity ratio of 0.53 confirm a predominantly elongated, structurally influenced basin geometry.
- The relief ratio of 0.082 confirms moderate terrain relief and gentle slope gradients, with higher dissection noted in the western and north-western sectors.
- Hypsometric analysis places the catchment in the mature geomorphic stage ($H_i = 0.46$), with an erosion integral of 54%, indicating substantial prior denudation.
- Sub-watershed prioritisation identifies SWS-1 and SWS-7 as demanding urgent soil conservation intervention, while SWS-8 represents the lowest erosion risk. Outcomes support targeted resource management and sustainable watershed governance across the study area.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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