

Integrated Morphometric Analysis for Erosion Susceptibility Assessment and Sub-Watershed Prioritisation in the Kamandala Naganadhi watershed of Palar Basin, Tamil Nadu, India

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Abstract

Morphometric analysis provides a quantitative framework for understanding drainage basin characteristics and their influence on hydrological response and erosion processes. The present study evaluates the Kamandala Naganadhi watershed using an integrated approach encompassing linear, areal, drainage texture, and relief morphometric parameters derived from Digital Elevation Model (DEM) data within a GIS environment. The results reveal significant spatial heterogeneity in basin geometry, drainage organisation, and terrain characteristics, which strongly influence runoff generation and sediment transport dynamics. Sub-watersheds exhibiting high drainage density, stream frequency, relief ratio, and ruggedness number demonstrate enhanced erosion susceptibility due to increased runoff velocity and reduced infiltration capacity. A compound factor (CF)-based prioritisation approach was employed to classify sub-watersheds into five categories ranging from very high to very low priority. Sub-watersheds 4C2A7c and 4C2A7d were identified as highly vulnerable zones requiring immediate intervention. The study highlights the effectiveness of morphometric analysis as a cost-efficient and scalable tool for watershed prioritisation and sustainable land and water resource management, particularly in data-scarce regions.

Keywords: Morphometric analysis; Drainage density; Erosion susceptibility; Watershed prioritization; GIS; Kamandala Naganadhi

1. Introduction

Morphometric analysis of drainage basins has long been recognised as a fundamental approach for understanding the interplay between geomorphology, hydrology, and erosion dynamics. Quantitative evaluation of basin characteristics provides critical insights into watershed behaviour, particularly in terms of runoff generation, sediment transport, and landscape evolution (Horton, 1945; Strahler, 1957; Schumm, 1956). The application of morphometric techniques, originally formalised through Hortonian laws and later refined by Strahler, enables systematic characterisation of drainage networks and their controlling

factors, including lithology, structural influences, and climatic conditions (Horton, 1945; Strahler, 1964; Chorley et al., 1957).

In recent decades, the integration of geospatial technologies such as Geographic Information Systems (GIS) and remote sensing has significantly enhanced the accuracy and efficiency of morphometric assessments. These tools facilitate the extraction of terrain and drainage parameters at multiple scales, enabling detailed evaluation of watershed heterogeneity and its implications for hydrological response and erosion susceptibility (Nag, 1998; Biswas et al., 1999; Javed et al., 2009). Such analyses are particularly valuable in data-scarce regions, where direct hydrological measurements are limited or unavailable (Sreedevi et al., 2009; Patel et al., 2013).

The Kamandala Naganathi watershed (Fig.1) exhibits pronounced variability in topography, drainage configuration, and basin geometry, making it an ideal case for morphometric investigation. Variations in linear, areal, drainage texture, and relief parameters across its sub-watersheds are expected to exert strong controls on runoff processes and erosion dynamics. Understanding these spatial variations is essential for identifying critical erosion-prone zones and developing targeted watershed management strategies (Miller, 1953; Smith, 1950).

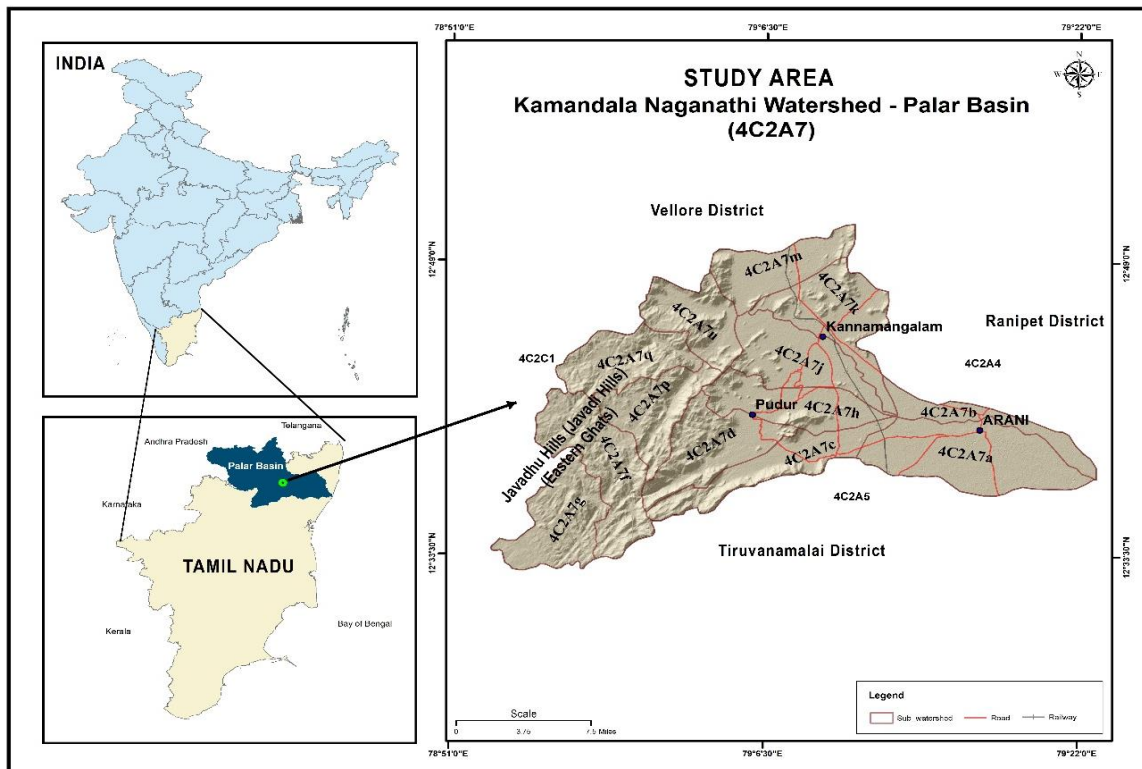


Figure 1 Study Area: Kamandala Naganathi Watershed – Palar Basin (4C2A7)

Although several studies have addressed morphometric characterisation of river basins, limited attention has been given to the integrated assessment of multiple morphometric domains (linear, areal, drainage texture, and relief) in relation to erosion prioritisation at the sub-watershed scale (Javed et al., 2009; Patel

et al., 2013). The present study aims to bridge this gap by providing a comprehensive morphometric

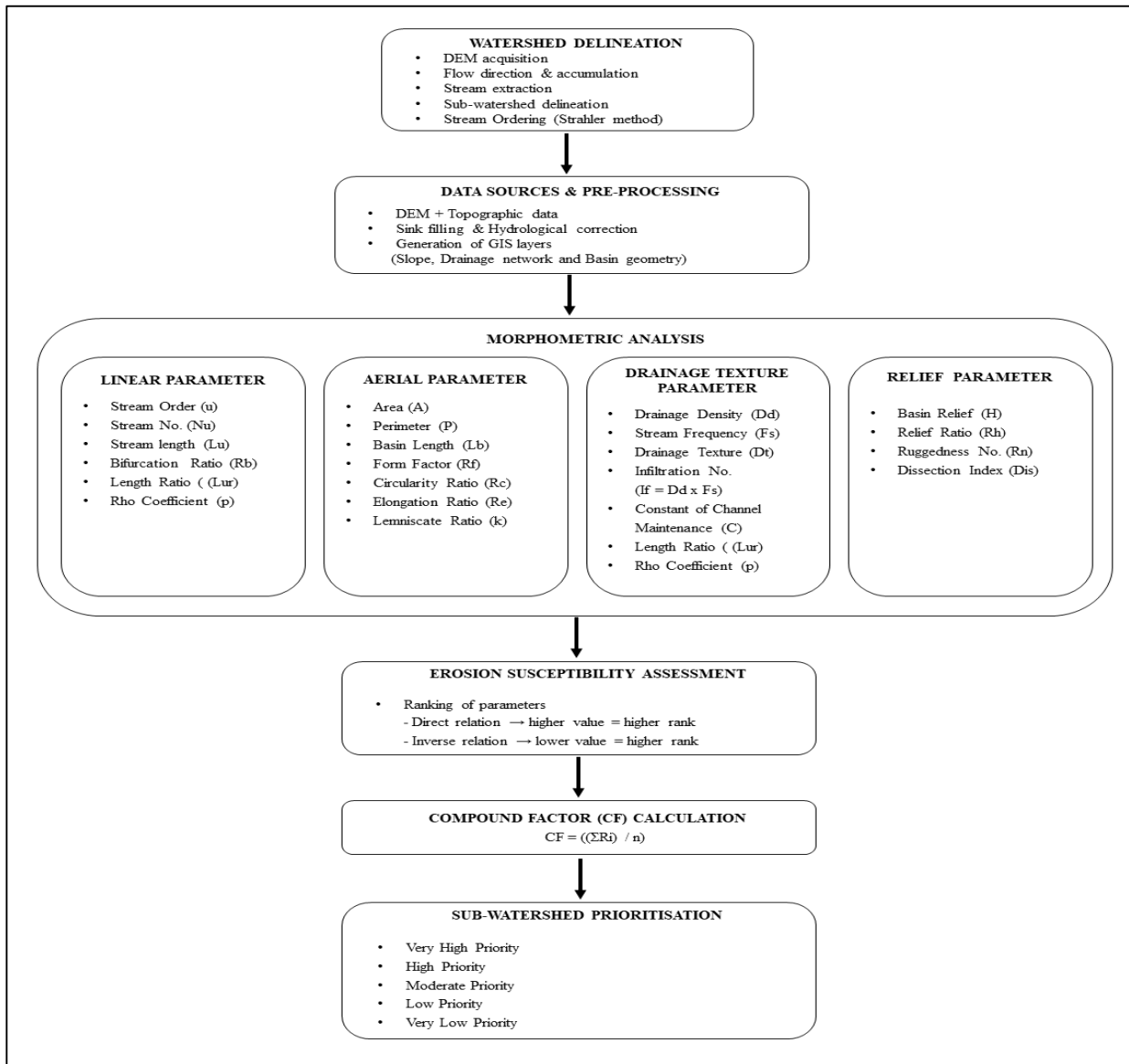


Figure 2 Methodology Flow Diagram for Sub-Watershed Prioritisation Using Morphometric Parameters

evaluation of the Kamandala Naganadhi watershed and linking these parameters to erosion susceptibility.

The specific objectives of this study are to:

- i. Quantify linear, areal, drainage texture, and relief morphometric parameters of the sub-watersheds,
- ii. analyse their influence on drainage organisation and hydrological response,
- iii. assess erosion susceptibility using a compound factor–based prioritization approach, and
- iv. Identify critical sub-watersheds requiring immediate soil and water conservation interventions.

2. Materials and Methods

Figure 2 and Table 1 present the sequence of steps in the workflow for morphometric evaluation and erosion-susceptibility assessment.



2.1 Watershed Delineation

The Kamandala Naganadhi watershed was delineated using high-resolution Digital Elevation Model (DEM) data within a Geographic Information System (GIS) environment. Standard hydrological analysis tools, including flow direction, flow accumulation, and stream network extraction, were employed to derive the watershed boundary and its constituent sub-watersheds (Jenson and Domingue, 1988; Tarboton, 1997). Stream ordering was performed following the hierarchical classification proposed by Strahler (1964), which provides a robust framework for analysing drainage network organisation and hierarchy.

	Morphometric Parameters	References	Formulae
Linear Parameter	Stream Order (U)	Strahler (1964)	Hierarchical rank
	Stream Number (Nu)	Horton (1945)	$Nu = N1+N2+\dots Nn$
	Stream Length (Lu)	Horton (1945)	Using ArcGIS Software
	Mean stream length (Lsm)	Strahler (1964)	$Lsm = Lu/Nu$
	Stream Length ratio (Lur)	Horton (1945)	$Lur = Lu/Lu-1$
	Mean Stream Length ratio (Lurm)		Average of Lur of all orders
	Bifurcation ratio (Rb)	Schumm (1956)	$Rb = Nu/Nu+1$
	Mean Bifurcation ratio (Rbm)	Strahler (1957)	Average of Rb of all orders
	Rho Coefficient (ρ)	Horton (1945)	$\rho = Lur / Rb$
Areal Parameters	Area (A) Sq km		
	Perimeter (P) km		
	Basin Length (Lb) Km		
	Mean Basin width (Wb)	Horton (1932)	$Wb = A/Lb$
	Lemniscate's (k)	Chorley (1957)	$k = Lb^2/A$
	Form factor ratio (Rf)	Horton (1932)	$Rf = A / Lb^2$
Drainage Texture Analysis	Drainage Density (Dd)	Horton (1932)	$Dd = Lu/A$
	Drainage Texture (Dt)	Horton (1945)	$Dt = Nu/P$
	Stream frequency (Fs)	Horton (1932)	$Fs = Nu/A$
	Circularity ratio (Rc)	Miller (1953)	$Rc = 12.57 * (A/P^2)$
	Elongation Ratio (Re)	Schumm (1956)	$Re = 2 (\sqrt{A/\pi})/Lb$
	Constant of channel maintenance (C)	Schumm (1956)	$C = 1/Dd$
	Infiltration number (If)	Faniran (1968)	$If = Fs * Dd$
Relief Characterization	Maximum Height of the basin (Z)/ Absolute Relief		
	Total Basin Relief (H)	Strahler (1952)	$H = Z - z$
	Relief ratio (Rh)	Schumm (1956)	$Rh = H/Lb$
	Dissection index (Dis)	Singh (1994)	$Dis = Z - z / Z$
	Ruggedness Number (Rn)	Strahler (1968)	$Rn = Dd * (H/1000)$

Table 1 Methodology Adopted for the Estimation and Computation of Morphometric Parameters

2.2 Data Sources and Pre-processing

The analysis was based on satellite-derived DEM data supplemented by topographic information. Before analysis, the DEM was pre-processed through sink filling and hydrological correction to eliminate spurious depressions and ensure flow continuity (Jenson and Domingue, 1988; Maidment, 2002). Subsequent GIS-based processing enabled the generation of derivative layers, including slope, drainage network, and basin geometry (Figures 3 & 4). All morphometric parameters were computed using standardised formulations to ensure methodological consistency, reproducibility, and comparability with established studies (Horton, 1945; Strahler, 1957).

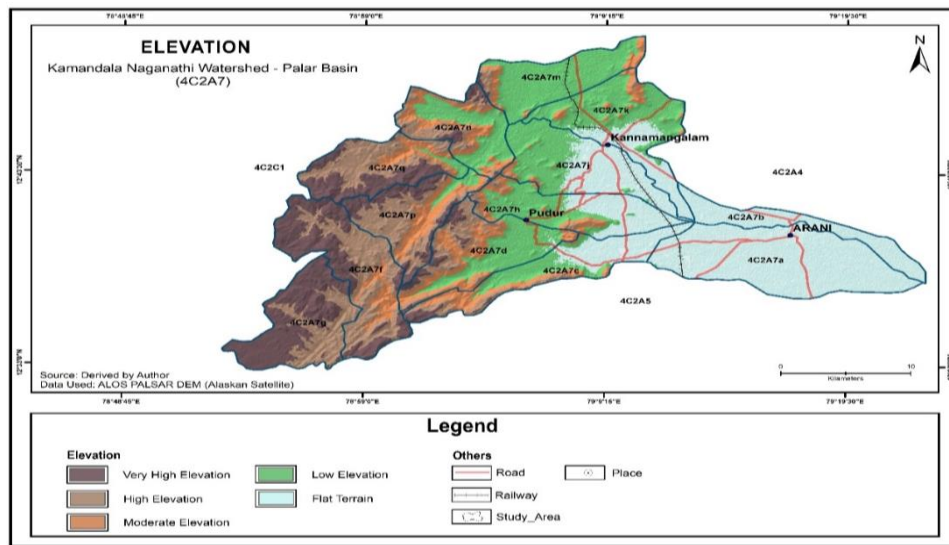


Figure 3 Elevation: Kamandala Naganathi Watershed – Palar Basin

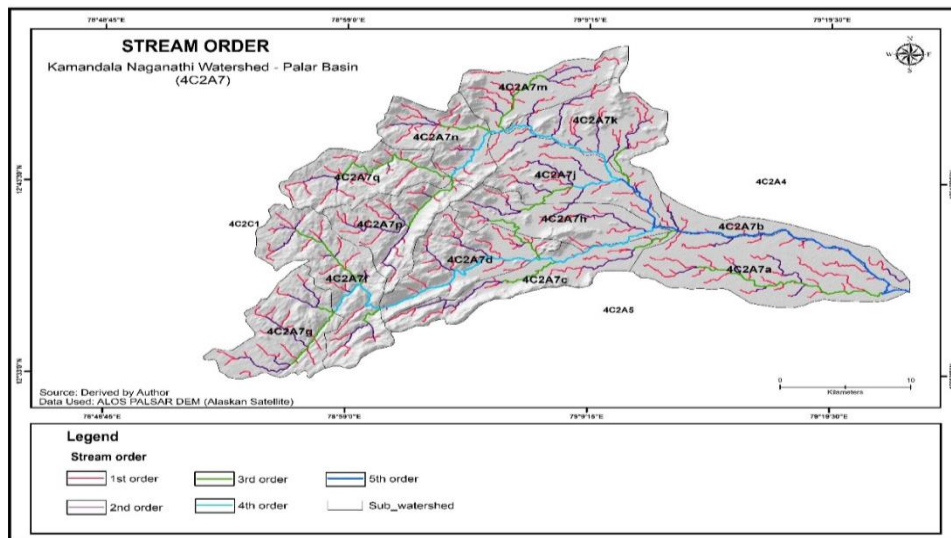


Figure 4 Stream order: Study Area: Kamandala Naganathi

2.3 Morphometric Analysis

Morphometric evaluation of the watershed was conducted by categorising parameters into four principal groups: linear, areal, drainage texture, and relief aspects. This classification follows conventional geomorphological frameworks widely adopted in watershed studies (Horton, 1945; Strahler, 1964; Schumm, 1956).

2.3.1 Linear Morphometric Parameters

Linear morphometric parameters characterise the structural configuration and hierarchical organisation of the drainage network. These include stream order (u), stream number (N_u), stream length (L_u), mean stream length (L_{sm}), stream length ratio (L_{ur}), bifurcation ratio (R_b), and rho coefficient (ρ) (Horton, 1945; Strahler, 1957).

The bifurcation ratio (R_b), defined as the ratio of the number of streams of a given order to those of the next higher order, was used to evaluate the degree of structural control and drainage branching characteristics (Strahler, 1964). Stream length ratio (L_{ur}) and rho coefficient (ρ) were employed to assess geomorphic maturity, basin development, and hydrological storage behaviour (Schumm, 1956; Horton, 1945).

2.3.2 Areal Morphometric Parameters

Areal morphometric parameters describe basin geometry and its influence on hydrological response. The parameters considered include basin area (A), perimeter (P), basin length (L_b), mean basin width (W_b), form factor (R_f), circularity ratio (R_c), elongation ratio (R_e), and lemniscate's ratio (k) (Miller, 1953; Chorley et al., 1957).

These indices play a crucial role in controlling runoff concentration, lag time, and peak discharge. In particular, form factor and circularity ratio were used to evaluate basin compactness and runoff potential, whereas elongation ratio and lemniscate's ratio provided insights into basin elongation and flow distribution characteristics (Miller, 1953; Schumm, 1956).

2.3.3 Drainage Texture Parameters

Drainage texture parameters were analysed to understand surface dissection and the balance between infiltration and runoff processes. The parameters include drainage density (D_d), stream frequency (F_s), drainage texture (D_t), constant of channel maintenance (C), and infiltration number (I_f) (Horton, 1945; Smith, 1950).

The infiltration number (I_f), computed as the product of drainage density and stream frequency, serves as a composite indicator of infiltration capacity and runoff potential (Faniran, 1968). Higher values of D_d , F_s , and I_f indicate enhanced runoff generation and erosion susceptibility, whereas higher values of the constant of channel maintenance (C) reflect increased infiltration and reduced channel development (Strahler, 1964).

2.3.4 Relief Morphometric Parameters

Relief morphometric parameters quantify the vertical dimension of the basin and its influence on erosion processes. The parameters include absolute relief (Z), basin relief (H), relief ratio (Rh), dissection index (Dis), and ruggedness number (Rn) (Schumm, 1956; Strahler, 1957).

These parameters were derived from elevation data to evaluate slope gradient, terrain ruggedness, and erosional energy. Relief ratio (Rh) was used as an indicator of basin steepness and runoff velocity, while ruggedness number (Rn), integrating relief and drainage density, provided a measure of overall terrain complexity and erosion potential (Strahler, 1964).

2.4 Erosion Susceptibility Assessment and Prioritisation

Erosion susceptibility was assessed using a multi-criteria ranking approach based on morphometric parameters (Biswas et al., 1999; Javed et al., 2009). Parameters exhibiting a direct relationship with erosion (e.g., Dd, Fs, Dt, Rh, Rn) were assigned higher ranks for higher values, whereas parameters inversely related to erosion (e.g., Re, Rc, C) were ranked in descending order (Patel et al., 2013).

A compound factor (CF) was computed for each sub-watershed as the average of the assigned ranks:

$$CF = \frac{\sum R_i}{n}$$

Where R_i represents the rank of the i^{th} parameter and n denotes the total number of parameters considered (Biswas et al., 1999).

Based on CF values, sub-watersheds were classified into five priority categories: very high, high, moderate, low, and very low. This classification provides a systematic and quantitative framework for identifying erosion-prone areas and guiding watershed management interventions (Javed et al., 2009).

2.5 Validation and Interpretation

The derived morphometric parameters were interpreted in the context of established geomorphological and hydrological principles (Strahler, 1957; Schumm, 1956). Cross-comparison among linear, areal, drainage texture, and relief parameters was performed to ensure consistency and robustness in the analysis. The prioritisation results were further evaluated for their applicability in soil and water conservation planning and sustainable watershed management (Sreedevi et al., 2009; Patel et al., 2013).

3. Linear Morphometric Controls on Drainage Organisation and Erosion Dynamics

The quantitative evaluation of linear morphometric parameters for the sub-watersheds of the Kamandala Naganadhi basin provides important insights into drainage architecture, geomorphic evolution, and associated hydrological responses. The observed distribution of stream order, stream number, and stream length largely conforms to established fluvial geomorphic laws, while deviations highlight localised controls of lithology, slope, and possible structural influences (Table 2).

The dominance of first-order streams (N1) across all sub-watersheds indicates a high degree of drainage dissection and surface runoff generation, which is characteristic of terrains with relatively low infiltration capacity and higher susceptibility to soil erosion. Sub-watersheds such as 4C2A7a, 4C2A7f, and 4C2A7k,

which exhibit notably higher counts of lower-order streams, reflect intense channel initiation processes and greater hydrological responsiveness, often associated with impermeable substrata or sparse vegetation cover.

Stream length (Lu) exhibits a generally decreasing trend with increasing stream order, consistent with Hortonian scaling laws; however, anomalies observed in certain sub-watersheds (e.g., 4C2A7d and 4C2A7k) suggest geomorphic disequilibrium, potentially arising from variations in slope gradient, lithological resistance, or localised tectonic adjustments. The relatively consistent values of mean stream length (Lsm) across stream orders indicate homogeneity in erosional processes and slope conditions, although minor variations point to differences in terrain roughness and channel gradient, which directly influence flow velocity and sediment transport capacity.

Table 2 Quantitative Morphometric Evaluation of Sub-Watersheds in the Kamandala Naganadhi Watershed Based on Linear, Areal, Relief, and Drainage Texture Indices

Morphometric Parameters		Stream order	Sub-watersheds of Kamandala Naganadhi												
			4C2A7a	4C2A7b	4C2A7c	4C2A7d	4C2A7f	4C2A7g	4C2A7h	4C2A7j	4C2A7k	4C2A7m	4C2A7n	4C2A7p	4C2A7q
Linear parameter	Stream Number (Nu)	N1	416	63	166	262	319	225	180	243	268	204	153	205	186
		N2	118	32	118	76	124	150	133	151	225	76	57	116	38
		N3	138	0	71	34	97	88	57	45	26	67	37	53	106
		N4	0	0	77	135	69	0	38	66	71	6	55	0	0
		N5	55	113	0	0	0	0	0	8	58	15	0	0	0
	Stream Length (Lu)	1	56.29	10.04	22.50	35.48	35.06	27.47	21.24	30.54	33.84	29.09	24.51	26.20	27.39
		2	14.42	4.01	16.08	9.04	14.68	18.21	18.34	19.43	24.10	10.98	7.47	15.03	5.39
		3	18.05	0.00	10.08	3.69	11.86	8.10	5.71	5.48	3.66	8.86	4.83	7.17	12.54
		4	0.00	0.00	8.32	16.24	7.80	0.00	3.74	8.07	9.88	0.63	6.28	0.00	0.00
		5	5.08	16.34	0.00	0.00	0.00	0.00	0.68	5.97	2.24	0.00	0.00	0.00	0.00
	Mean stream length (Lsm)	N1	0.14	0.16	0.14	0.14	0.11	0.12	0.12	0.13	0.13	0.14	0.16	0.13	0.15
		N2	0.12	0.13	0.14	0.12	0.12	0.12	0.14	0.13	0.11	0.14	0.13	0.13	0.14
		N3	0.13	0.00	0.14	0.11	0.12	0.09	0.10	0.12	0.14	0.13	0.13	0.14	0.12
		N4	0.00	0.00	0.11	0.12	0.11	0.00	0.10	0.12	0.14	0.11	0.11	0.00	0.00
		N5	0.09	0.14	0.00	0.00	0.00	0.00	0.02	0.04	0.04	0.00	0.00	0.00	0.00
	Stream Length ratio (Lur)	Order 2/1	0.26	0.4	0.72	0.25	0.41	0.66	0.86	0.63	0.71	0.37	0.3	0.57	0.19
		Order 3/2	1.25	0	0.63	0.41	0.81	0.44	0.31	0.28	0.15	0.8	0.64	0.47	2.32
		Order 4/3	0	0	0.82	4.41	0.65	0	0.65	1.47	2.69	0.07	1.3	0	0
		Order 5/4	0	0	0	0	0	0	0.18	0.74	0.22	0	0	0	0
		Mean Stream Length ratio (Lurm)	0.5	0.2	0.54	1.27	0.47	0.28	0.5	0.78	0.94	0.31	0.56	0.26	0.84
Bifurcation ratio (Rb)	Order 1/2	3.53	1.97	1.41	3.45	2.57	1.5	1.35	1.61	1.19	2.68	2.68	1.77	4.89	
	Order 2/3	0.86	0	1.66	2.24	1.28	1.7	2.33	3.36	8.65	1.13	1.54	2.19	0.36	
	Order 3/4	0	0	0.92	0.25	1.41	0	1.5	0.68	0.37	11.17	0.67	0	0	
	Order 4/5	0	0	0	0	0	0	0	8.25	1.22	0.4	0	0	0	
Mean Bifurcation ratio (Rbm)	1.46	0.98	1.33	1.98	1.75	1.07	1.73	3	2.86	3.85	1.63	1.32	1.75		
Rho Coefficient (ρ)	0.34	0.2	0.41	0.64	0.27	0.26	0.29	0.26	0.26	0.33	0.08	0.34	0.2	0.48	

The stream length ratio (Lur) demonstrates considerable variability, reflecting heterogeneous basin development and differing stages of geomorphic evolution. Elevated Lur values in sub-watersheds such as 4C2A7d, 4C2A7k, and 4C2A7q indicate steeper channel gradients and youthful topographic conditions, which enhance runoff velocity and erosive power. In contrast, lower Lur values correspond to more mature geomorphic stages, characterised by subdued slopes and relatively stabilised drainage systems. The mean stream length ratio (Lurm) further corroborates the non-uniformity of basin evolution, suggesting that the watershed is undergoing differential geomorphic development.

The bifurcation ratio (Rb), a critical indicator of drainage network branching and structural control, predominantly falls within moderate ranges across the sub-watersheds, implying that drainage development is largely governed by natural geomorphic processes rather than strong tectonic influence. However, relatively higher mean bifurcation ratios (Rbm) observed in sub-watersheds such as 4C2A7j, 4C2A7k, and 4C2A7m may indicate localised structural disturbances or lithological heterogeneity,

leading to irregular channel branching patterns. Conversely, lower Rbm values in sub-watersheds like 4C2A7b and 4C2A7g suggest more stable geomorphic conditions and less structural interference.

The rho coefficient (ρ), representing the relationship between stream length ratio and bifurcation ratio, provides a useful measure of hydrological storage capacity and basin response characteristics. Sub-watersheds with higher ρ values (e.g., 4C2A7d and 4C2A7q) are indicative of enhanced storage capacity, delayed peak discharge, and relatively attenuated runoff response, which may reduce immediate erosion intensity. In contrast, lower ρ values (e.g., 4C2A7m) signify limited storage, rapid hydrological response, and higher runoff efficiency, thereby increasing the likelihood of flash flooding and accelerated soil erosion.

The linear morphometric parameters indicate that the Kamandala Naganadhi watershed is characterised by a predominantly dendritic drainage pattern with spatial heterogeneity in geomorphic maturity and hydrological behaviour. Sub-watersheds exhibiting high stream frequency, elevated Lur, and moderate-to-high Rbm are particularly prone to enhanced runoff and erosion processes, whereas those with lower bifurcation ratios and higher rho coefficients tend to exhibit greater hydrological stability and reduced erosion susceptibility.

4. Aerial Morphometric Controls on Basin Geometry and Erosion Response

The aerial morphometric attributes of the sub-watersheds in the Kamandala Naganadhi basin provide critical insights into basin geometry, runoff generation mechanisms, and their implications for erosion susceptibility. Parameters such as basin area (A), perimeter (P), basin length (Lb), mean basin width (Wb), lemniscate's ratio (k), and form factor (Rf) collectively define the spatial configuration of drainage units and govern their hydrological behaviour (Table 3).

The basin area exhibits notable variability across the sub-watersheds, indicating heterogeneity in runoff-generating potential and sediment yield. Larger sub-watersheds (e.g., 4C2A7a and 4C2A7f) are capable

Table 3 | Quantitative Morphometric Evaluation of Sub-Watersheds in the Kamandala Naganadhi Watershed Based on Areal, Relief, and Drainage Texture Indices

Morphometric Parameters		Sub-watersheds of Kamandala Naganadhi												
		4C2A7a	4C2A7b	4C2A7c	4C2A7d	4C2A7f	4C2A7g	4C2A7h	4C2A7j	4C2A7k	4C2A7m	4C2A7n	4C2A7p	4C2A7q
Aerial Parameter	Area (A) Sq km	103.54	32.4	56.72	65.29	80.27	64.02	55.54	64.23	68.44	51.63	49.94	53.65	54.92
	Perimeter (P) km	49.38	48.52	54.81	42.67	52.38	40.49	41	44.87	52.07	35.83	34.06	39.66	36.56
	Basin Length (Lb) Km	19.2	21.36	24.42	15.33	16.75	10.48	17.21	11.7	15.1	13.6	8.73	10.65	14.56
	Mean Basin width (Wb)	5.39	1.52	2.32	4.26	4.79	6.11	3.23	5.49	4.53	3.8	5.72	5.04	3.77
	Lemniscate's (k)	3.56	14.08	10.51	3.6	3.5	1.72	5.33	2.13	3.33	3.58	1.53	2.11	3.86
	Form factor ratio (Rf)	0.28	0.07	0.1	0.28	0.29	0.58	0.19	0.47	0.3	0.28	0.66	0.47	0.26
Drainage Texture Analysis	Drainage Density (Dd)	0.91	0.94	1	0.99	0.86	0.84	0.9	1.08	1.08	0.96	0.86	0.9	0.83
	Drainage Texture (Dt)	14.72	4.29	7.88	11.88	11.63	11.43	9.95	11.43	12.45	10.27	8.87	9.43	9.03
	Stream frequency (Fs)	7.02	6.42	7.61	7.77	7.59	7.23	7.35	7.99	9.47	7.13	6.04	6.97	6.01
	Circularity ratio (Rc)	0.53	0.17	0.24	0.45	0.37	0.49	0.42	0.4	0.32	0.51	0.54	0.43	0.52
	Elongation Ratio (Re)	0.6	0.3	0.35	0.6	0.6	0.86	0.49	0.77	0.62	0.6	0.91	0.78	0.57
	Constant of channel maintenance (C)	1.1	1.06	1	1.01	1.16	1.19	1.12	0.93	0.93	1.04	1.16	1.11	1.22
	Infiltration number (If)	6.39	6.03	7.61	7.69	6.53	6.07	6.54	8.63	10.23	6.84	5.19	6.27	4.93
Relief Characterization	Maximum Height of the basin (Z)/ Absolute Relief	262	180	977	984	986	958	771	651	637	826	880	1070	1019
	Total Basin Relief (H)	155	73	825	785	626	426	613	499	488	603	650	812	763
	Relief ratio (Rh)	0.008	0.003	0.034	0.051	0.037	0.041	0.036	0.043	0.032	0.044	0.074	0.076	0.052
	Dissection index (Dis)	0.59	0.41	0.84	0.8	0.63	0.44	0.8	0.77	0.77	0.73	0.74	0.76	0.75
	Ruggedness Number (Rn)	0.14	0.07	0.83	0.78	0.54	0.36	0.55	0.54	0.53	0.58	0.56	0.73	0.63

of generating greater runoff volumes and sustained flow, thereby enhancing sediment transport capacity over longer durations. In contrast, smaller basins (e.g., 4C2A7b) tend to respond more rapidly to rainfall events but contribute relatively lower total discharge. However, erosion intensity is not solely dependent on basin size; rather, it is strongly influenced by basin shape and drainage configuration.

The relationship between basin length (L_b) and perimeter (P) reflects the degree of basin elongation and boundary irregularity. Sub-watersheds such as 4C2A7b and 4C2A7c, characterised by relatively longer basin lengths, exhibit elongated geometries, which are typically associated with delayed hydrological response, longer concentration time, and attenuated peak discharge. This configuration reduces the immediate erosive force of runoff. Conversely, sub-watersheds with shorter basin lengths and comparatively compact perimeters (e.g., 4C2A7g and 4C2A7n) tend to have more compact basin shapes, promoting rapid runoff concentration and higher peak flows, thereby increasing erosion susceptibility.

Mean basin width (W_b) further complements the interpretation of basin geometry. Wider basins (e.g., 4C2A7g and 4C2A7n) facilitate rapid lateral flow convergence, which may intensify peak discharge under high-intensity rainfall conditions. In contrast, narrower basins (e.g., 4C2A7b and 4C2A7c) distribute flow over longer pathways, reducing runoff concentration rates and associated erosive energy.

The lemniscate's ratio (k) serves as a robust indicator of basin shape and flow concentration characteristics. High k values observed in sub-watersheds such as 4C2A7b and 4C2A7c confirm pronounced elongation, which is typically linked to reduce peak flow and moderated erosion processes. On the other hand, lower k values (e.g., 4C2A7g and 4C2A7n) indicate near-circular basin configurations, which are known to produce short lag times, rapid hydrological response, and increased peak discharge, thereby enhancing erosion potential.

The form factor (R_f) corroborates the influence of basin shape on hydrological response. Sub-watersheds with higher R_f values (e.g., 4C2A7n, 4C2A7g, and 4C2A7j) approach a circular geometry, resulting in flashy runoff behaviour and higher erosive power. In contrast, lower R_f values (e.g., 4C2A7b, 4C2A7c, and 4C2A7h) represent elongated basins, which are characterised by lower peak flows distributed over longer durations, thereby reducing immediate erosion risk.

Overall, the aerial morphometric analysis indicates that basin shape exerts a dominant control on runoff concentration and erosion dynamics, often outweighing the influence of basin size alone. Sub-watersheds with circular geometry (high R_f , low k , wider W_b) are particularly vulnerable to flash floods and accelerated soil erosion, whereas elongated basins demonstrate hydrological attenuation and relative geomorphic stability.

These findings emphasise the importance of incorporating aerial morphometric parameters into watershed prioritisation frameworks. The results provide a scientific basis for targeted soil and water conservation planning, where compact and circular sub-watersheds should be prioritised for structural interventions, while elongated basins may require more preventive and management-oriented strategies.

5. Drainage Texture as a Control on Runoff Generation and Erosion Susceptibility

The drainage texture parameters of the Kamandala Naganadhi sub-watersheds provide a coherent picture of the basin's hydro-geomorphic behaviour and its implications for erosion processes. The integrated assessment of drainage density (Dd), stream frequency (Fs), drainage texture (Dt), circularity ratio (Rc), elongation ratio (Re), constant of channel maintenance (C), and infiltration number (If) highlights pronounced spatial variability in runoff response and sediment mobilisation potential (Table 3).

Drainage density values across the basin fall within a moderate range, indicating a transitional hydrological regime where both infiltration and surface runoff processes are active. However, relatively higher Dd values observed in sub-watersheds such as 4C2A7j and 4C2A7k suggest closely spaced channel networks, which are typically associated with reduced infiltration capacity, higher surface runoff, and increased erosive energy. This inference is reinforced by corresponding high stream frequency (Fs) values, particularly in 4C2A7k, indicating intense channel development and efficient runoff concentration, conditions that are conducive to enhanced soil erosion and sediment transport.

Drainage texture (Dt) further refines the understanding of surface dissection and lithological control. Sub-watersheds such as 4C2A7a, 4C2A7d, and 4C2A7k exhibit relatively high Dt values, indicative of fine drainage texture, which generally develops under impermeable subsurface conditions and higher slope gradients. Such environments promote rapid runoff generation and increased erosion susceptibility. In contrast, lower Dt values observed in sub-watersheds like 4C2A7b and 4C2A7c reflect coarser drainage texture, suggesting relatively permeable materials, higher infiltration rates, and reduced erosional intensity.

Basin shape parameters, particularly circularity ratio (Rc) and elongation ratio (Re), play a critical role in modulating runoff timing and peak discharge characteristics. Sub-watersheds with higher Rc values (e.g., 4C2A7n and 4C2A7a) tend toward circular geometries, which facilitate rapid hydrological response, shorter lag time, and higher peak flows, thereby increasing the likelihood of erosion. Conversely, sub-watersheds with lower Rc values (e.g., 4C2A7b and 4C2A7c) exhibit elongated basin shapes, which promote delayed runoff concentration and attenuated peak discharge, resulting in comparatively lower erosion potential. The elongation ratio (Re) corroborates this interpretation, with higher values indicating near-circular basins and lower values reflecting elongated forms with more regulated flow regimes.

The constant of channel maintenance (C), being inversely related to drainage density, provides additional insight into the infiltration capacity and channel development threshold of the basin. Sub-watersheds such as 4C2A7q and 4C2A7g, which exhibit higher C values, require a larger surface area to sustain channel formation, indicating lower drainage development, higher infiltration, and reduced erosion susceptibility. In contrast, lower C values in sub-watersheds like 4C2A7j and 4C2A7k reflect dense channel networks and limited infiltration, conditions that favour rapid runoff and increased erosion.

The infiltration number (If), a composite indicator derived from drainage density and stream frequency, effectively captures the runoff–infiltration balance. Higher If values observed in sub-watersheds such as 4C2A7k and 4C2A7j indicate low infiltration capacity and high runoff potential, which significantly

enhance erosion risk. Conversely, lower I_f values (e.g., 4C2A7q and 4C2A7n) suggest greater infiltration and subdued runoff response, thereby reducing the intensity of erosion processes.

Overall, the drainage texture analysis demonstrates that linear and texture-related parameters (D_d , F_s , D_t , I_f) exert a strong positive control on erosion susceptibility, while parameters indicative of infiltration capacity (C) and basin elongation (low R_c , moderate R_e) tend to mitigate erosive processes. The coexistence of fine-textured, high-runoff sub-watersheds alongside coarser, infiltration-dominated units underscores the hydro-geomorphic heterogeneity of the basin.

These findings emphasise the importance of incorporating drainage texture parameters into watershed prioritisation frameworks. Sub-watersheds characterised by high drainage density, stream frequency, and infiltration number, coupled with low channel maintenance values, should be prioritised for structural and vegetative soil conservation measures. In contrast, sub-watersheds with favourable infiltration characteristics may be managed through preventive land-use planning and monitoring strategies. Overall, the results reaffirm the utility of morphometric analysis as a quantitative and scalable approach for erosion assessment and watershed management in data-scarce environments.

6. Relief Controls on Runoff Dynamics and Erosion Susceptibility

Relief characteristics exert a primary control on the hydrological response and erosion dynamics of the Kamandala Naganadhi sub-watersheds. The spatial variability in absolute relief (Z), total basin relief (H), relief ratio (R_h), dissection index (Dis), and ruggedness number (R_n) reflects marked heterogeneity in terrain configuration, which directly influences slope processes, runoff velocity, and sediment transport (Table 3).

The distribution of absolute relief (Z) indicates pronounced elevation contrasts across the watershed, with higher values observed in sub-watersheds such as 4C2A7p and 4C2A7q. These elevated terrains are typically associated with steeper slopes and higher gravitational energy, which enhance runoff acceleration and increase the detachment and transport capacity of flowing water. Correspondingly, total basin relief (H) is significantly higher in sub-watersheds such as 4C2A7c, 4C2A7d, and 4C2A7p, indicating substantial vertical differentiation within these basins. Such conditions favour active fluvial incision and increased sediment yield, particularly under high-intensity rainfall.

The relief ratio (R_h) serves as a sensitive indicator of basin steepness and hydrological responsiveness. Higher R_h values observed in sub-watersheds such as 4C2A7p and 4C2A7n suggest steep channel gradients and rapid concentration of runoff, which are conducive to enhanced erosive power and channel deepening. In contrast, sub-watersheds with low R_h values (e.g., 4C2A7a and 4C2A7b) are characterised by gentler slopes, longer flow paths, and reduced runoff velocity, resulting in comparatively lower erosion potential.

The dissection index (Dis) provides insight into the degree of vertical incision relative to total relief and serves as a proxy for geomorphic maturity. High Dis values (e.g., 4C2A7c, 4C2A7d, and 4C2A7h) indicate intensely dissected terrain, reflecting advanced stages of landscape evolution and sustained fluvial activity. These sub-watersheds are likely to experience continuous slope adjustment and sediment mobilisation.

Conversely, lower Dis values (e.g., 4C2A7b and 4C2A7g) suggest less dissected and relatively stable terrain, where erosional processes are less dominant.

The ruggedness number (Rn), which integrates relief and drainage density, effectively captures the combined influence of slope steepness and drainage intensity. Sub-watersheds such as 4C2A7c, 4C2A7d, and 4C2A7p exhibit high Rn values, indicating highly rugged and dissected landscapes with significant topographic complexity. These conditions promote rapid runoff, high stream power, and increased susceptibility to soil erosion and mass wasting processes. In contrast, lower Rn values (e.g., 4C2A7a and 4C2A7b) reflect smoother terrain with lower energy conditions, where erosion processes are comparatively subdued.

Overall, the relief parameters demonstrate a strong positive control on erosion susceptibility, with increasing elevation range, slope gradient, and terrain ruggedness leading to enhanced runoff velocity and sediment transport capacity. The co-occurrence of high Rh, Dis, and Rn values in several sub-watersheds highlights zones of geomorphic instability and active erosion, which warrant priority in watershed management planning.

From a management perspective, sub-watersheds characterised by high relief, steep gradients, and strong dissection should be targeted for structural interventions such as check dams, slope stabilisation measures, and vegetative reinforcement to mitigate erosion and regulate runoff. In contrast, sub-watersheds with lower relief and gentler slopes may be managed through preventive land-use strategies and conservation practices.

In summary, the relief-based morphometric assessment underscores the critical role of vertical terrain characteristics in controlling hydrological processes and erosion dynamics, reinforcing the need to integrate relief parameters into multi-criteria watershed prioritisation frameworks for sustainable land and water resource management.

7. Result and Discussion

The present morphometric analysis of the Kamandala Naganadhi watershed demonstrates a strong linkage between basin characteristics and spatial variability in erosion susceptibility. The ranking and prioritisation based on compound factor (CF) values provide a robust framework for identifying critical sub-watersheds requiring immediate management intervention (Table 4).

Sub-watersheds categorised under very high priority (4C2A7c and 4C2A7d) exhibit distinctly higher values of drainage density (Dd), stream frequency (Fs), and drainage texture (Dt), indicating a highly dissected drainage network. Such conditions are typically associated with low infiltration capacity, impermeable subsurface conditions, and high runoff generation, which collectively intensify soil erosion. The elevated ruggedness number (Rn) and relief ratio (Rh) further confirm the presence of steep slopes and high relief energy, contributing to increased flow velocity and enhanced sediment detachment and transport. These findings are consistent with established hydrological principles, where higher linear and relief parameters correlate positively with erosion intensity Figure 4.

Table 4: Morphometric Parameter-Based Ranking and Prioritisation of Sub-Watersheds Using Compound Factor (CF) Analysis

Sub-watersheds	Morphometric Parameter-Based Ranking of Sub-Watersheds																			CF	Priority
	Morphometric Parameters with Direct Relationship to Erosion									Morphometric Parameters with inverse relation to erosion											
	Dd	Fs	Dt	If	Rh	Rn	Dis	p	Bh	Rbm	Rf	Rc	Re	k	c	A	Lb	P	Total		
4C2A7a	7	5	13	6	2	2	3	9.5	2	9	8	2	7	7	7	1	3	4	97.5	5.4	Very Low
4C2A7b	8	3	1	3	1	1	1	2.5	1	13	13	13	13	1	8	13	2	5	102.5	5.7	Very Low
4C2A7c	11	10	2	10	4	13	13	11	13	10	12	12	12	2	11	7	1	1	155	8.6	Very High
4C2A7d	10	11	11	11	10	12	11.5	13	11	4	8	6	7	5	10	4	6	7	157.5	8.8	Very High
4C2A7f	3.5	9	10	7	6	5.5	4	6	8	5.5	6	10	7	8	3.5	2	5	2	108	6.0	Very Low
4C2A7g	2	7	8.5	4	7	3	2	4.5	3	12	2	5	2	12	2	6	12	9	103	5.7	Very Low
4C2A7h	5.5	8	6	8	5	7	11.5	7	7	7	11	8	11	3	5	8	4	8	130	7.2	Moderate
4C2A7j	12.5	12	8.5	12	8	5.5	9.5	4.5	5	2	3.5	9	4	10	12.5	5	10	6	139.5	7.8	High
4C2A7k	12.5	13	12	13	3	4	9.5	8	4	3	5	11	5	9	12.5	3	7	3	137.5	7.6	High
4C2A7m	9	6	7	9	9	9	5	1	6	1	8	4	7	6	9	11	9	12	128	7.1	Moderate
4C2A7n	3.5	2	3	2	12	8	6	9.5	9	8	1	1	1	13	3.5	12	13	13	120.5	6.7	Low
4C2A7p	5.5	4	5	5	13	11	8	2.5	12	11	3.5	7	3	11	6	10	11	10	138.5	7.7	High
4C2A7q	1	1	4	1	11	10	7	12	10	5.5	10	3	10	4	1	9	8	11	118.5	6.6	Low

The high-priority sub-watersheds (4C2A7j, 4C2A7k, and 4C2A7p) also demonstrate relatively elevated morphometric indices, although slightly lower than the very high category. The morpho-dynamic behaviour in these units suggests moderately high runoff and erosion potential, likely driven by a combination of moderate slope gradients and well-developed channel networks. These areas may act as transitional zones where erosion processes are active but less extreme.

In contrast, moderate priority sub-watersheds (4C2A7h and 4C2A7m) reflect a more balanced morphometric configuration. Moderate drainage density and relief conditions indicate controlled hydrological response, where runoff generation is less intense and infiltration processes are comparatively more effective. However, these areas remain vulnerable to episodic erosion under high-intensity rainfall events, particularly in regions with disturbed land use.

Sub-watersheds falling under low and very low priority categories (e.g., 4C2A7a, 4C2A7b, 4C2A7f, 4C2A7g, 4C2A7n, and 4C2A7q) are characterised by lower values of drainage density, stream frequency, and relief parameters, indicating less dissection and reduced runoff potential. These conditions promote higher infiltration rates and reduced erosive force, thereby minimising soil loss. Additionally, relatively higher values of shape parameters such as elongation ratio (Re), circularity ratio (Rc), and form factor (Rf) in some of these sub-watersheds suggest elongated basin geometry, which typically results in delayed peak flow and lower flood intensity, further reducing erosion risk.

The compound factor (CF) approach effectively integrates multiple morphometric indicators, allowing for a comprehensive and comparative assessment of erosion susceptibility across sub-watersheds. Higher CF

values correspond to areas with greater geomorphic instability, necessitating priority in watershed management planning. The results reinforce the conceptual understanding that linear parameters (Dd, Fs, Dt) and relief parameters (Rh, Rn) exhibit a direct relationship with erosion, whereas areal/shape parameters (Rf, Rc, Re) generally show an inverse relationship.

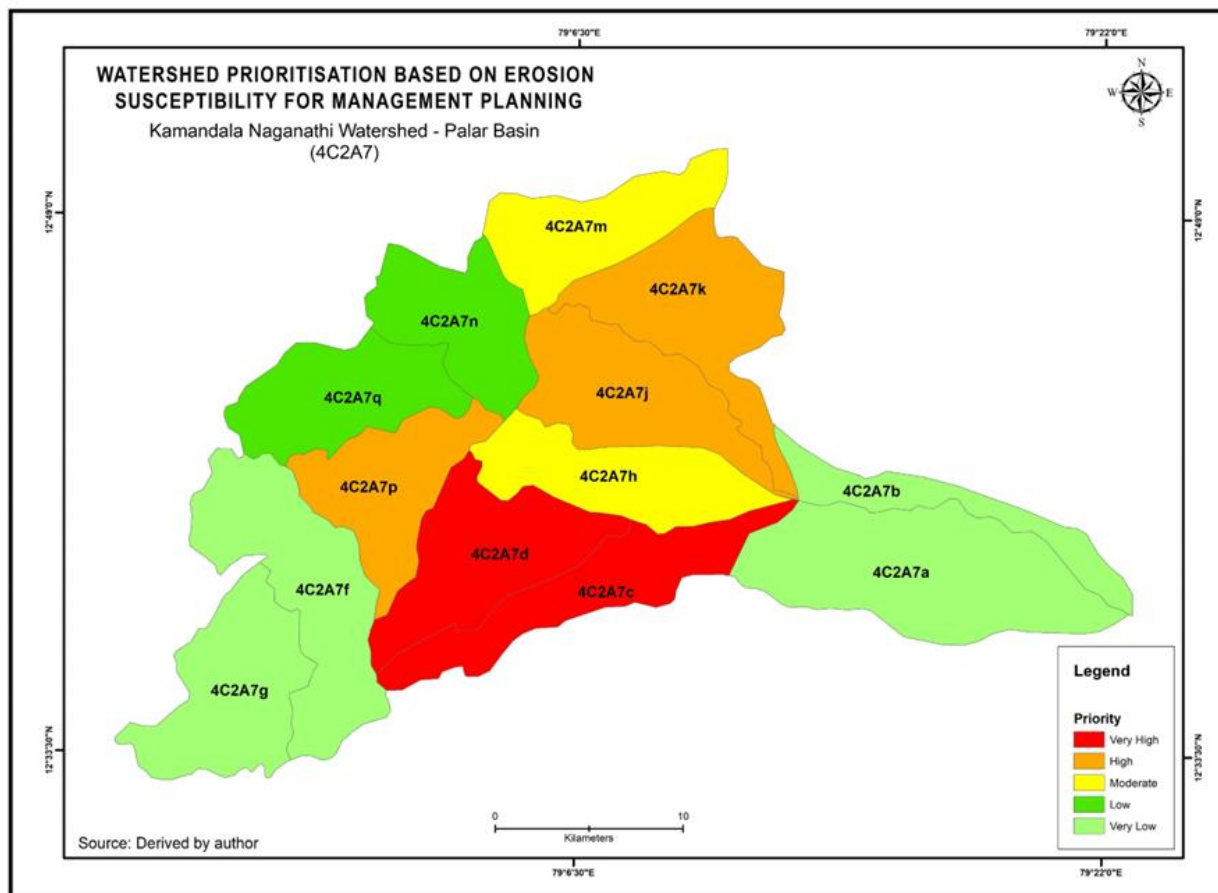


Figure 4 Watershed prioritisation based on erosion susceptibility for management

The compound factor (CF) based prioritisation provides a scientifically robust basis for implementing graded, process-oriented watershed interventions aligned with erosion susceptibility. Sub-watersheds classified under very high and high priority categories, characterized by elevated drainage density, stream frequency, infiltration number, and relief, require immediate and intensive soil and water conservation measures to control rapid runoff and severe erosion; these include structural interventions such as check dams, gabion structures, gully plugs, and contour bunding, combined with biological measures like vegetative barriers, afforestation, and stream bank stabilization to enhance slope stability and groundwater recharge. Moderate priority sub-watersheds, representing transitional hydro-geomorphic conditions, benefit from preventive and adaptive strategies such as mulching, conservation tillage, crop rotation, controlled grazing, and small-scale water harvesting structures aimed at maintaining soil integrity and regulating runoff. In contrast, low and very low priority sub-watersheds, which exhibit relatively stable conditions with lower erosion risk and higher infiltration capacity, should be managed through sustainable land-use practices, soil fertility management, periodic monitoring, and conservation of existing vegetation cover, with minimal structural intervention. Overall, this hierarchical intervention framework ensures

optimal resource allocation, reduces sediment yield, enhances hydrological stability, and promotes long-term watershed sustainability under varying environmental conditions.

8. Conclusion

The present study demonstrates that morphometric analysis, when integrated with geospatial techniques, provides a robust, quantitative, and cost-effective framework for assessing erosion susceptibility and prioritising sub-watersheds, particularly in data-scarce environments. The systematic evaluation of linear, areal, drainage texture, and relief parameters enabled the identification of spatial variability in hydro-geomorphic characteristics and their direct influence on runoff generation and erosion processes.

The prioritisation approach based on the compound factor (CF) proved effective in delineating critical sub-watersheds that are more vulnerable to soil erosion and land degradation. Sub-watersheds exhibiting higher drainage density, stream frequency, infiltration number, and relief characteristics were found to have greater erosion susceptibility, necessitating immediate soil and water conservation interventions. Conversely, sub-watersheds with favourable morphometric attributes indicated relatively lower erosion risk and greater infiltration potential.

The findings underscore the significance of morphometric indices as surrogate indicators of hydrological response and landscape evolution, enabling informed decision-making in watershed management. The integration of GIS-based analysis enhances spatial accuracy and reproducibility, making the approach scalable and adaptable to other ungauged or poorly monitored basins.

The study provides a scientific basis for prioritising watershed management strategies, supporting sustainable land and water resource planning under changing environmental conditions. Future research may focus on integrating morphometric analysis with field-based observations, sediment yield data, and advanced modelling techniques to further refine erosion assessment and improve the reliability of watershed management interventions.

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