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Geomorphology and Resource Inventory of Watersheds for Sustainable Land Use in Cagayan de Oro City, Mindanao, Philippines

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Abstract

Water and land are critical natural resources that require effective management, particularly in rapidly urbanizing areas such as Cagayan de Oro City, Philippines. This study aims to assess erosion susceptibility and prioritize conservation needs across nine watersheds using GIS-based morphometric analysis. The entire extent of each watershed was analyzed beyond political boundaries to ensure comprehensive evaluation of geomorphological characteristics. Key morphometric parameters, including drainage density, stream frequency, slope, and basin shape, were computed to determine watershed behavior and erosion risk. Results indicate that the Cagayan de Oro River Basin is the most erosion-prone, followed by the Umalag, Iponan, and Cugman watersheds, while the Bugo–Alae watershed exhibits the lowest susceptibility. Higher slope gradients and elongated basin shapes were associated with increased erosion risk, whereas higher drainage density and stream frequency corresponded to lower susceptibility. These findings provide a scientific basis for prioritizing watershed management and conservation strategies, supporting sustainable land use planning and erosion mitigation in the study area.

Keywords: watershed management; morphometric analysis; erosion susceptibility; GIS; conservation planning; land use planning; river basin prioritization

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1. Introduction

Water and land resources are fundamental to human survival and socio-economic development. In rapidly urbanizing regions such as Cagayan de Oro City, Philippines, the sustainable management of these resources has become increasingly critical due to population growth, land use change, and the intensifying impacts of climate change [1–3]. Watersheds play essential ecological and socio-economic roles, including water supply, flood regulation, irrigation, and biodiversity support [4,5]. However, these systems are increasingly threatened by environmental degradation, particularly soil erosion and altered hydrological processes [6,7].

Watershed degradation is commonly driven by unsustainable land use practices, deforestation, and unregulated development, especially in upland areas where agricultural expansion and settlements increase erosion susceptibility [8,9]. These pressures compromise watershed integrity and reduce their capacity to support both human and ecological systems. Despite existing conservation efforts, many studies have focused only on portions of watersheds constrained by administrative boundaries, resulting in incomplete assessments and limited applicability for integrated watershed management.

Morphometric analysis provides a quantitative approach to evaluating watershed characteristics and erosion potential by analyzing drainage basin geometry [10,11]. The integration of Geographic Information Systems (GIS) enhances this approach by enabling efficient computation and spatial

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visualization of key parameters such as drainage density, bifurcation ratio, relief, and stream frequency [12–14]. Recent studies have demonstrated the effectiveness of combining morphometric analysis and GIS techniques in identifying erosion-prone areas and prioritizing watersheds for conservation [15–17].

This study applies GIS-based morphometric analysis to nine watersheds traversing Cagayan de Oro City, considering their full spatial extent beyond administrative boundaries. A total of 19 morphometric parameters were analyzed to assess erosion susceptibility and establish a prioritization framework for watershed management. The results identify critical watersheds that require immediate conservation and intervention and provide a scientific basis for sustainable land use planning and watershed management in the region.

2. Materials and Methods

2.1. Study Area

The study was conducted in nine watersheds traversing Cagayan de Oro City, Philippines, namely Bungcalalan, Iponan, Cagayan de Oro River Basin, Bigaan, Cugman, Umalag, Agusan, Tagpangi Creek, and Bugo–Alae. These watersheds were analyzed in their entirety, extending beyond administrative boundaries to ensure a comprehensive assessment of their geomorphological characteristics.

Cagayan de Oro City is located between 8°14′00″ to 8°31′00″ N latitude and 124°27′00″ to 124°49′00″ E longitude. The area is characterized by diverse topography, ranging from upland mountainous regions to lowland urban zones, making it susceptible to erosion, flooding, and land degradation

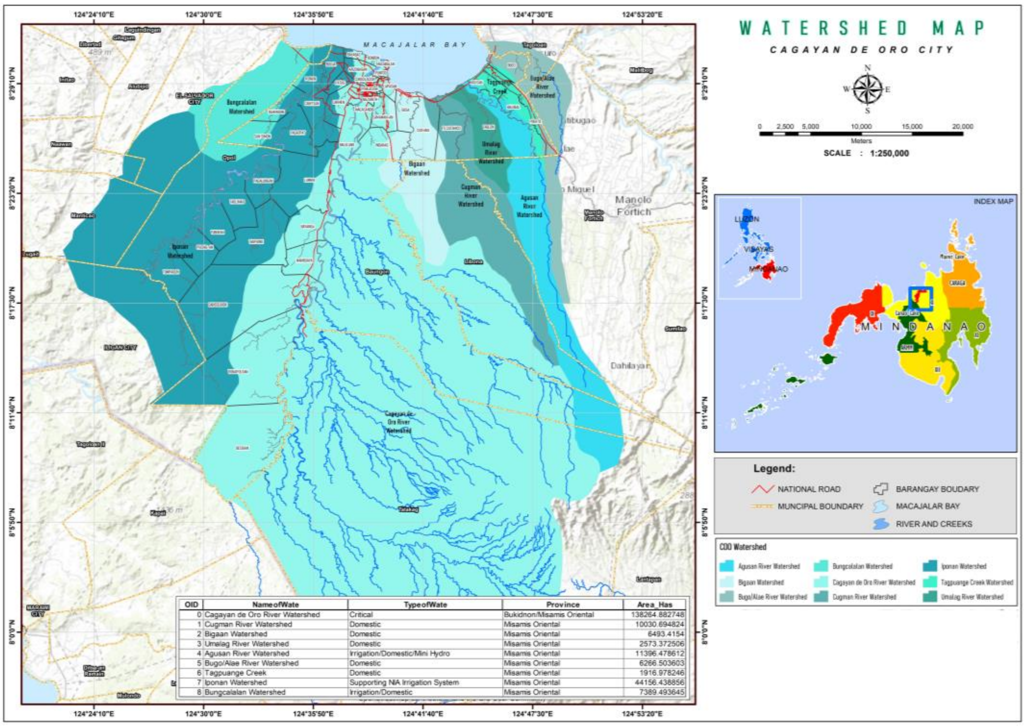

Figure 1. Location and extent of the nine watersheds in Cagayan de Oro City, Philippines (data source: CPDO; adapted and processed by the authors).

2.2. Data Sources

This study utilized secondary data sources, including Digital Elevation Model (DEM) data obtained from the National Mapping and Resource Information Authority (NAMRIA) and the

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Department of Environment and Natural Resources (DENR Region X). The DEM has a spatial resolution of 10 m with a vertical accuracy of approximately 1.0 m.

Additional datasets such as land use maps, watershed boundaries, and drainage networks were derived using GIS and remote sensing techniques.

2.3. GIS Processing and Watershed Delineation

Watershed delineation and drainage network extraction were performed using ArcGIS 10.2. Hydrological analysis tools, including flow direction, flow accumulation, and stream definition, were applied to generate stream networks.

The Strahler stream ordering method was used to classify stream hierarchy. DEM preprocessing involved projection to a local coordinate system and sink filling to ensure accurate hydrological modeling. Watershed boundaries were delineated based on defined outlet points and threshold values.

2.4. Morphometric Analysis

A total of 19 morphometric parameters were computed and categorized into linear, areal, and relief aspects. These include parameters such as stream order, bifurcation ratio, drainage density, stream frequency, basin relief, and slope. The formulas used for the computation of these parameters are presented in Table 1.

Table 1. Morphometric parameters, formulas, and references used in the analysis.

Parameter	Formula	Reference
Basic Parameters		
Area (A)	GIS analysis / DEM	
Perimeter (P)	GIS analysis / DEM	
Basin length (Lb)	Lb = 1.312 $A^{0.568}$	Schumm (Munoth and Goyal, 2020)
Mean basin width (Wb)	Wb = A / Lb	Horton (Radwan et al., 2020)
Stream order (U)	Hierarchical rank of streams using Strahler method	Strahler (Munoth and Goyal, 2020)
Stream number (Nu)	Nu = N1 +N2 +...+Nn	Horton (Potter, 1957)
Linear parameters		
Stream length (Lu)	Length of the stream	Strahler (Jaiswal et al., 2015)
Mean stream length (Lsm)	Lsm = Lu / Nu	Strahler (Jaiswal et al., 2015)
Stream length ratio (Lur)	Lur =Lu / Lu-1 Lu – Total stream length of order 'u' Lu-1 - Total stream length of next lower order	Strahler (Jaiswal et al., 2015)
Bifurcation ratio (Rb)	Rb= Nu / Nu+1 Nu – Total number stream segments of order 'u' Nu+1 -	Strahler (Jaiswal et al., 2015)

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	Total number stream segments of next higher order Rb= Nu / Nu+1 Nu – Total number stream segments of order 'u' Nu+1 - Total number stream segments of next higher order	
Mean stream length ratio (Rslm)	Rslm = Σ Lur / n	Schumm (Munoth and Goyal, 2020)
Mean bifurcation ratio (Rbm)	Rbm = Σ Rb / n	Schumm (Munoth and Goyal, 2020)
Rho coefficient (ρ)	ρ = Rslm / Rbm	Horton (Potter, 1957)
Drainage density (Dd)	Dd = Lu / A	Horton (Radwan et al., 2020)
Stream frequency (Fs)	Fs = Σ Nu / A	Horton (Radwan et al., 2020)
Drainage texture (Dt)	Dt = Nu / P	Horton (Potter, 1957)
Infiltration number (If)	If = Fs ∗ Dd	Faniran (Strahler, 1957)
Length of overland flow (Lof)	Lof = 1 / (2Dd)	Horton (Potter, 1957)
Drainage intensity (Di)	Di = Fs / Dd	Faniran (Strahler, 1957)
Aerial parameters		
Form factor ratio (Ff)	Rf = A / Lb 2	Horton (Radwan et al., 2020)
Elongation ratio (Re)	Re = (1.128 $A^{0.5}$) / Lb	Schumm (Munoth and Goyal, 2020)
Circularity ratio (Rc)	Rc = 12.57 (A / P^2)	Miller (MR et al., 2019)
Lemniscate's ratio (k)	k = Lb 2 / 4A	Chorley (Jothimani et al., 2020)
Compactness constant (Cc)	Cc = 0.282 P / $A^{0.5}$	Horton (Potter, 1957)
Shape factor (Sf)	Sf = Lb 2 / A	Nooka Ratnam (Rahaman et al., 2015)
Relief parameters		
Elevation of basin outlet (z)	GJS analysis I DEM	
Maximum elevation of the basin (Z)	GJS analysis I DEM	
Total basin relief (H)	H = Z – z	Strahler (Munoth and Goyal, 2020)
Relief ratio (Rh)	Rh = H / Lb	Schumm (Munoth and Goyal, 2020)
Relative relief (Rr)	Rr = H / P	Schumm (Munoth and Goyal, 2020)
Ruggedness number (Rn)	Rn = H * Dd	Strahler (Munoth and Goyal, 2020)

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The overall workflow of the GIS-based morphometric analysis and watershed prioritization is presented in Figure 2.

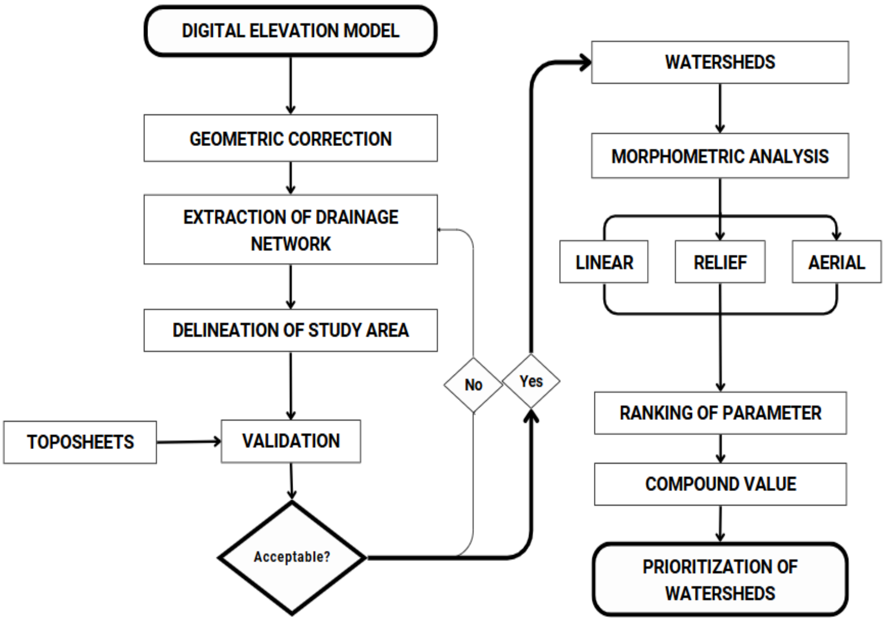

Figure 2. Flowchart representing the methodological process.

2.5. Watershed Prioritization

Watershed prioritization was conducted using the compound parameter method. Morphometric parameters directly related to erosion susceptibility (e.g., drainage density, stream frequency, bifurcation ratio) were ranked accordingly, while parameters with inverse relationships (e.g., form factor, circularity ratio) were ranked inversely.

The compound value for each watershed was computed by averaging the ranks of all parameters. Watersheds with higher compound values were classified as more susceptible to erosion and prioritized for conservation and management interventions.

2.6. Data Analysis and Visualization

The computed morphometric parameters were analyzed to evaluate erosion susceptibility across the watersheds. GIS-based spatial analysis and visualization techniques were used to map watershed characteristics and identify high-risk areas.

The results were interpreted to support watershed management planning and to provide a scientific basis for land use decision-making in Cagayan de Oro City.

3. Results and Discussions

3.1. Morphometric Characteristics of Watersheds

The morphometric analysis of the nine watersheds in Cagayan de Oro City revealed significant variations in stream order, stream length, bifurcation ratio (Rb), and stream length ratio (Rl). Among the watersheds, the Cagayan de Oro River Basin (CDORB) exhibited the highest cumulative stream length (1,921.60 km) and stream number (Nu = 1,431), indicating its dominant hydrological contribution within the study area.

High bifurcation ratio values, particularly in the Iponan Watershed (Rb = 56.41), suggest strong structural control and possible geological disturbances influencing stream development. These variations reflect differences in watershed response, drainage efficiency, and erosion susceptibility.

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The computed stream order, stream number, stream length, bifurcation ratio, and stream length ratio are summarized in Table 2.

Table 2. Stream order, stream number, stream length, bifurcation ratio (Rb), and stream length ratio (Rl) of the watersheds.

Code of Watershed	Stream number (N_u)	Stream length (L_u)	Bifurcation ratio (R_b)	Stream length ratio (R_l)
BWS	2,687	254.6	7.6	3.39
IWS	778	558.2	56.41	1.99
CDORB	1,431	1,921.60	9.1	2.8
BiWS	1,070	251.4	8.9	2.9
CWS	737	327.6	7.16	4.18
UWS	239	69.9	4.99	2.85
AWS	727	350.3	7.36	2.38
TsCR	37	20	4.18	1.75
TbCR	47	29.3	3.1	2.92
B/AWS	408	198.7	8.08	2.18

*BWS = Bungcalan Watershed; IWS = Iponan Watershed; CDORB = Cagayan de Oro River Basin; BiWS = Bigaan Watershed; CWS = Cugman Watershed; UWS = Umalag Watershed; AWS = Agusan Watershed; TsCR = Tagpuange (small) creek; TbCR = Tagpuange (big) creek; B/AWS = Bugo/Alae Watershed.

3.2. Basic and Linear Morphometric Parameters

The basic morphometric parameters, including watershed area, perimeter, basin length, and stream order, provide fundamental insights into watershed geometry and hydrological behavior. Larger watersheds, such as CDORB, are associated with higher runoff potential due to increased catchment area.

Stream order and stream number further indicate drainage network complexity. Watersheds with higher stream orders exhibit more developed drainage systems, while a higher number of first-order streams suggests greater surface runoff and erosion susceptibility. The basic morphometric parameters of the watersheds are summarized in Table 3.

Table 3. Basic morphometric parameters of the watersheds.

	BWS	IWS	CDORB	BiWS	CWS	UWS	AWS	TsCR	TbCR	B/AWS
A	6,410.52	41,514.10	144,534.75	6,182.37	9,498.15	2,507.96	10,571.08	536.76	959.38	5,837.95
P	45.02	134.84	224.19	50.64	77.71	32.53	97.33	16.97	30.73	74.5
L_b	1.90	5.93	13.6	2.19	1.85	1.31	1.73	0.6	0.56	1.37
W_b	33.70	70	106.3	28.2	51.32	19.21	61.13	9	17.11	42.47
U	5	5	6	6	5	4	5	3	3	5

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N_u	2,687	778	1,431	1,070	737	239	727	37	47	408

**A = watershed area; P = watershed perimeter; Lb = Basin Length; Wb = mean basin width; U = stream order.

Linear parameters such as stream length (Lu), stream length ratio (Rl), and bifurcation ratio (Rb) reflect watershed evolution and structural influence. The computed rho coefficient (ϱ), which integrates stream length and bifurcation ratio, indicates variations in storage capacity and drainage efficiency among the watersheds. The computed linear morphometric parameters are presented in Table 4.

Table 4. Linear morphometric parameters of the watersheds.

	BWS	IWS	CDORB	BiWS	CWS	UWS	AWS	TsCR	TbCR	B/AWS
L_u	**254.6**	**558.2**	**1,921.60**	**251.4**	**327.6**	**69.9**	**350.3**	**20**	**29.3**	**198.7**
R_l	3.39	1.99	2.80	2.90	4.18	2.85	2.38	1.75	2.92	2.18
R_b	7.60	56.41	9.10	8.90	7.16	4.99	7.36	4.18	3.10	8.08
ϱ	0.45	0.04	0.32	0.34	0.59	0.57	0.32	0.42	0.94	0.27

**ϱ = Rho coefficient.

3.3. Areal Morphometric Parameters and Erosion Susceptibility

Areal parameters, including stream frequency (Fs), drainage density (Dd), drainage texture (Dt), and infiltration number (If), provide insights into runoff characteristics and erosion potential. Lower drainage density and stream frequency values observed in several watersheds indicate higher infiltration capacity but may also reflect reduced drainage efficiency.

Higher values of drainage intensity (Di) and infiltration number (If) suggest increased surface runoff, which contributes to soil erosion. Basin shape parameters such as circularity ratio (Rc), elongation ratio (Re), and form factor (Ff) further influence hydrological response. Elongated watersheds tend to have delayed peak flow but may exhibit higher erosion susceptibility depending on slope and land cover conditions. The computed areal morphometric parameters of the watersheds are presented in Table 5.

Table 5. Areal Morphometric Parameters .

	BWS	IWS	CDORB	BiWS	CWS	UWS	AWS	TsCR	TbCR	B/AWS
F_s	0.4	0.02	0.01	0.17	0.08	0.1	0.07	0.07	0.05	0.07
D_d	0.04	0.01	0.01	0.04	0.03	0.03	0.03	0.04	0.03	0.03
D_t	60.00	6	6	21	9	7	7	2	2	5
L_{of}	12.59	37.19	37.61	12.29	14.49	17.95	15.09	13.45	16.39	14.69
D_i	10.60	1.4	0.7	4.3	2.2	3.4	2.1	1.9	1.6	2.1
I_f	0.02	0.00	0.00	0.01	0.003	0.003	0.002	0.003	0.001	0.002
R_c	0.40	0.29	0.36	0.3	0.198	0.298	0.14	0.234	0.128	0.132
R_e	4.75	3.88	3.15	4.05	5.94	4.33	6.71	4.38	6.23	6.27
F_f	17.72	11.8	7.82	12.86	27.73	14.72	35.35	15.09	30.51	30.9

K	0.01	0.02	0.03	0.02	0.009	0.017	0.007	0.017	0.008	0.008
C_c	2	1.87	1.66	1.82	2.249	1.832	2.67	2.066	2.798	2.75
S_f	0.00	0.08	0.13	0.08	0.036	0.068	0.028	0.066	0.033	0.032
C	25	100	100	25	33	33	33	25	33	33

**Fs = stream frequency; Dd = Drainage density; Dt = drainage texture; Lof = Length of overland flow; Di = Drainage intensity; If = infiltration number; Rc = circularity ratio; Re = elongation ratio; Ff = Form factor ratio; K = Lemniscate's ratio; Cc = Compactness constant; Sf = shape factor; C = constant of channel maintenance.

3.4. Relief Characteristics

Relief parameters, including total basin relief (H), relief ratio (Rh), and ruggedness number (Rn), indicate the topographic influence on watershed processes. Watersheds with higher relief values are more prone to erosion due to steeper slopes and increased gravitational force acting on soil materials.

The results show that watersheds with high relief and ruggedness values are associated with greater erosion risk, particularly in upland areas where slope gradients are significant. The computed relief parameters of the watersheds are presented in Table 6.

Table 6. Relief Parameters of watershed.

	BWS	IWS	CDORB	BiWS	CWS	UWS	AWS	TsCR	TbCR	B/AWS
H	2,870	1,103	2,884	720	1,034	809	2,603.40	335.6	484.8	562
R_f	0.06	0.01	0.01	0.01	0.013	0.025	0.027	0.02	0.016	0.008
R_h	1.51	0.19	0.21	0.33	0.559	0.62	1.505	0.563	0.865	0.409
R_n	0.11	0.01	0.04	0.03	0.036	0.023	0.086	0.012	0.015	0.019

**H = total basin relief; R_h = Relief ratio; R_f = relative relief; R_n = ruggedness number.

3.5. Watershed Prioritization

Watershed prioritization was conducted using the compound parameter method, where lower compound values indicate higher susceptibility to erosion and higher priority for conservation. The final ranking of the watersheds is presented in Table 7.

The results indicate that the Cagayan de Oro River Basin (CDORB) has the highest priority, followed by the Umalag (UWS) and Iponan (IWS) watersheds. These watersheds are characterized by higher relief, steeper slopes, and greater susceptibility to erosion.

Moderate priority watersheds include Cugman (CWS), Tagpuange Creek (TbCR), Bungcalan (BWS), and Agusan (AWS), which exhibit moderate morphometric characteristics and erosion potential. In contrast, Bigaan (BiWS), Tagpuange Creek (TsCR), and Bugo–Alae (B/AWS) watersheds were classified as low priority due to their relatively stable geomorphological characteristics and lower erosion susceptibility.

These findings highlight the importance of targeted watershed management, particularly in high-priority areas, to mitigate erosion and support sustainable land use planning.

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Table 7. Final Ranking of Watersheds.

Watershed	Linear Compounded Value	Linear Rank	Aerial Compounded Value	Aerial Rank	Relief Compounded Value	Relief Rank	Final Rank (Overall)
BWS	3.813333333	6	10.27153846	8	717.92	9	V
IWS	19.48	10	12.50461538	10	275.8025	7	III
CDORB	4.073333333	9	12.11384615	9	721.065	10	I
BiWS	4.046666667	8	6.303076923	2	180.0925	4	VI
CWS	3.976666667	7	7.305	5	258.652	6	IV
UWS	2.803333333	3	6.365230769	3	202.417	5	II
AWS	3.353333333	4	7.861307692	7	651.2545	8	V
TsCR	2.116666667	1	4.947384615	1	84.04875	1	VII
TbCR	2.32	2	7.136769231	4	121.424	2	IV
B/AWS	3.51	5	7.306461538	6	140.609	3	VIII

3.6. Implications for Watershed Management

The results highlight the need for targeted conservation and management strategies in high-priority watersheds. Immediate interventions such as reforestation, soil conservation measures, and land use regulation are recommended to mitigate erosion and enhance watershed sustainability.

The prioritization framework developed in this study provides a scientific basis for decision-making and supports sustainable land use planning in Cagayan de Oro City.

4. Conclusions

This study applied GIS-based morphometric analysis to evaluate the erosion susceptibility of nine watersheds in Cagayan de Oro City. The results revealed significant variations in morphometric parameters, including drainage density, bifurcation ratio, stream frequency, and basin relief, reflecting differences in hydrological behavior and erosion potential among the watersheds.

The Cagayan de Oro River Basin and Umalag Watershed were identified as the most susceptible to erosion, indicating the need for priority conservation and management interventions. In contrast, the Bugo–Alae Watershed and Tagpuange Creek (small) exhibited lower susceptibility due to more favorable morphometric characteristics.

The findings demonstrate that morphometric analysis is an effective tool for watershed prioritization and provides a scientific basis for sustainable land use planning and erosion mitigation. The results can support decision-makers in implementing targeted conservation strategies to improve watershed management in Cagayan de Oro City.

Future research may incorporate additional factors such as land cover, soil properties, and rainfall intensity to enhance the accuracy of erosion assessment.

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Data Availability Statement: The data used in this study are available from the corresponding author upon reasonable request. Some datasets were obtained from the City Planning and Development Office (CPDO) of Cagayan de Oro City and the Department of Environment and Natural Resources (DENR Region X) and may be subject to data sharing restrictions.

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Abbreviations

The following abbreviations are used in this manuscript:

AWS	Agusan Watershed
B/AWS	Bugo/Alae Watershed
BiWS	Bigaan Watershed
BWS	Bungcalalan Watershed
CDO	Cagayan de Oro
CDORB	Cagayan de Oro River Basin
CLENRO	City Local Environment and Natural Resources Office
CPDO	City Planning and Development Office
CV	Compound Value
DEM	Digital Elevation Model
DENR	Department of Environment and Natural Resources
ELCCAP	Enhanced Local Climate Change Action Plan
EnP	Environmental Planner
GIS	Geographic Information System
GPS	Global Positioning System
IWS	Iponan Watershed
LGU	Local Government Unit
NAMRIA	National Mapping and Resource Information Authority
ORI	Orthorectified Radar Image
SDG	Sustainable Development Goal
TbCR	Tagpuange Big Creek Watershed

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TsCR Tagpuange Small Creek Watershed

UWS Umalag Watershed

Appendix A. Morphometric Parameter Equations

Detailed formulas used in the morphometric analysis are provided in Appendix A (Table A1).

Table A1. Morphometric parameters, formulas, and descriptions used in the analysis.

Parameter	Formula	Description
Area (A)	GIS analysis / DEM	Total surface area of the watershed
Perimeter (P)	GIS analysis / DEM	Outer boundary length of the watershed
Basin length (L_b)	Lb = 1.312 A0.568	Longest dimension of the basin
Mean basin width (W_b)	$W_b = A / L_b$	Average width of the watershed
Stream order (U)	Hierarchical rank of streams using Strahler method	Hierarchical level of streams
Stream number (N_u)	$N_u = N_1+N_2+...+N_n$	Total number of streams
Stream length (L_u)	Measured using GIS tools	Total length of all stream segments within the watershed
Mean stream length (L_{sm})	Lsm = Lu / Nu	Average stream segment length
Stream length ratio (L_{ur})	Lur =Lu / Lu-1	Ratio of stream length of a given order to its next lower order
	L_u – Total stream length of order 'u'	
	L_{u-1} - Total stream length of next lower order	
Bifurcation ratio (R_b)	Rb= Nu / Nu+1 N_u – Total number stream segments of order 'u' N_{u+1} - Total number stream segments of next higher order	Ratio of number of streams of a given order to next higher order
	Rslm = ∑ Lur / n	
	$R_{bm} = \sum R_b / n$	
	ρ = Rslm / Rbm	
Mean stream length ratio (R_{slm})	$D_d = L_u / A$	Average of stream length ratios across all stream orders
Mean bifurcation ratio (R_{bm})	$F_s = \sum N_u / A$	Average bifurcation ratio across all stream orders

Rho coefficient (ϱ)	$D_t = N_u / P$	Indicates storage capacity and development stage of drainage system
Drainage density (D_d)	Rb= Nu / Nu+1 N_u – Total number stream segments of order 'u' N_{u+1} - Total number stream segments of next higher order	Total stream length per unit watershed area
Stream frequency (F_s)	Rslm = ∑ Lur / n	Number of streams per unit area
Drainage texture (D_t)	$R_{bm} = \sum R_b / n$	Indicates relative dissection and surface roughness
Infiltration number (I_f)	If = Fs * Dd	Represents infiltration capacity of the basin
Length of overland flow (L_{of})	$L_{of} = 1 / (2D_d)$	Distance runoff travels before entering a stream
Drainage intensity (D_i)	Di = Fs / Dd	Indicates the degree of stream development relative to drainage density
Form factor ratio (F_f)	Rf = A / Lb2	Indicates basin shape (elongated or circular)
Elongation ratio (R_e)	$R_e = (1.128\ A^{0.5}) / L_b$	Shape of basin relative to a circle
Circularity ratio (R_c)	$R_c = 12.57\ (A / P^2)$	Roundness of the watershed
Lemniscate's ratio (k)	$k = L_b^2 / 4A$	Shape and slope of basin
Compactness constant (C_c)	$C_c = 0.282\ P / A^{0.5}$	Watershed compactness
Shape factor (S_f)	Sf = Lb2 / A	Indicates basin elongation
Elevation of basin outlet (z)	GIS analysis / DEM	The lowest elevation point where water exits the watershed
Maximum elevation of the basin (Z)	GIS analysis / DEM	The highest elevation point within the watershed
Total basin relief (H)	$H = Z – z$	Elevation difference from the highest point to the outlet
Relief ratio (R_h)	$R_h = H / L_b$	Slope steepness of the watershed
Relative relief (R_r)	$R_r = H / P$	Relief in relation to perimeter
Ruggedness number (R_n)	$R_n = H * D_d$	Combines relief and drainage density to assess erosion risk

Appendix B. Stream Order, Stream Number, and Stream Length of Watersheds

Table A2. Detailed stream order, stream number (Nu), stream length (Lu), bifurcation ratio (Rb), and stream length ratio (Rl) of the watersheds.

Stream Order**	Code of Watershed*									
	BWS	**IWS**	**CDORB**	**BiWS**	**CWS**	**UWS**	**AWS**	**TsCR**	**TbCR**	**B/AWS**
N_u	2,687	778	1,431	1,070	737	239	727	37	47	408
Nu1	1,474	391	719	537	370	120	364	19	24	205
Nu2	644	174	345	251	175	57	147	5	11	86
Nu3	288	108	192	130	87	27	100	13	12	59
Nu4	132	103	87	73	34	35	79	-	-	43
Nu5	149	2	41	47	71	-	37	-	-	15
Nu6	-	-	47	32	-	-	-	-	-	-
L_u	254.6	558.2	1,921.60	251.4	327.6	69.9	350.3	20	29.3	198.7
Lu1	119.7	269.9	937.2	122.3	143.3	31.31	159.5	11.87	11.29	96.27
Lu2	58.0	127.1	508.3	62.8	91.9	14.41	83.7	3.27	5.19	40.56
Lu3	33.1	89.9	258.6	27.3	59.9	8.64	47.5	4.81	12.79	35.4
Lu4	15.2	66.5	106.5	21.9	8.7	15.49	42.9	-	-	20.09
Lu5	28.60	4.8	58.3	9.3	23.9	-	16.7	-	-	6.34
Lu6	-	-	52.75	7.9	-	-	-	-	-	-
Nun/Nun+1 = Rb	7.60	56.41	9.10	8.90	7.16	4.99	7.36	4.18	3.10	8.08

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Rb1	2.29	2.25	2.1	2.1	2.11	2.11	2.48	3.8	2.18	2.38
Rb2	2.24	1.61	1.8	1.9	2.01	2.11	1.47	0.38	0.92	1.46
Rb3	2.18	1.05	2.2	1.8	2.56	0.77	1.27	-	-	1.37
Rb4	0.89	51.5	2.1	1.6	0.48		2.14	-	-	2.87
Rb5	-	-	0.9	1.5	-	-	-	-	-	-
Lu/Lun-1 = Rl	3.39	1.99	2.80	2.90	4.18	2.85	2.38	1.75	2.92	2.18
Rl1	1.88	0.07	0.9	0.8	2.75	1.79	0.39	1.47	2.46	0.32
Rl2	0.46	0.74	0.5	0.4	0.14	0.6	0.9	0.28	0.46	0.57
Rl3	0.57	0.71	0.4	0.8	0.65	0.46	0.57	-	-	0.87
Rl4	0.48	0.47	0.5	0.4	0.64		0.52	-	-	0.42
Rl5	-	-	0.5	0.5	-	-	-	-	-	-

*BWS = Bungcalan Watershed; IWS = Iponan Watershed; CDORB = Cagayan de Oro River Basin; BiWS = Bigaan Watershed; CWS = Cugman Watershed; UWS = Umalag Watershed; AWS = Agusan Watershed; TsCR = Tagpuange (small) creek; TbCR = Tagpuange (big) creek; B/AWS = Bugo/Alae Watershed **Nu = Stream number; Lu = Stream Length; Rb = Bifurcation Ratio; Rl = Stream Length Ratio.

Appendix C. List of Watersheds: Bungcalan Watershed; Iponan Watershed; Cagayan de Oro River Basin; Bigaan Watershed; Cugman Watershed; Umalag Watershed; Agusan Watershed; Tagpuange Creek; Bugo–Alae Watershed.

Table A3. Watershed Descriptions and Corresponding Figures.

Watershed	**Description**
Bungcalalan Watershed	The Bungcalalan Watershed is located in the northeastern part of Cagayan de Oro City. It is an essential water source for nearby agricultural areas and plays a key role in mitigating flooding in its surrounding regions (Jones, 2018).

Iponan Watershed	The Iponan Watershed is one of the largest watersheds in Cagayan de Oro City. It is vital for both urban and rural water supply and contributes significantly to the local ecosystem, supporting various plant and animal species (Smith et al., 2020).
Cagayan de Oro River Basin	The Cagayan de Oro River Basin is the most significant water body in the region, encompassing several sub-watersheds. It is crucial for flood control and the overall water supply of Cagayan de Oro City, as well as for agricultural and industrial activities (Jones, 2018).
Bigaan Watershed	Located in the central part of Cagayan de Oro City, the Bigaan Watershed supports several agricultural zones. It is particularly important for managing water flow during the rainy season, reducing the risk of flooding in downstream areas (Smith et al., 2020).
Cugman Watershed	The Cugman Watershed provides water for both irrigation and domestic use in Cagayan de Oro. It is a crucial area for biodiversity, home to a variety of flora and fauna that support the local ecological balance (Jones, 2018).
Umalag Watershed	The Umalag Watershed is vital for flood control, particularly during heavy rains. Its forested areas act as natural barriers to erosion, while the watershed also serves as an important resource for nearby agricultural and urban development (Smith et al., 2020).
Agusan Watershed	The Agusan Watershed is located in the southern portion of Cagayan de Oro City. It plays a major role in water quality improvement and serves as a natural filtration system for water before it enters the Cagayan de Oro River (Jones, 2018).
Tagpuange Creek (Big & Small)	Tagpuange Creek is a small but significant water source for the agricultural zones nearby. It is important for the overall hydrological balance of the region and serves as a critical drainage system during monsoon seasons (Smith et al., 2020).
Bugo/Alae Watershed	The Bugo/Alae Watershed provides water for both agricultural and urban needs in the region. It is a significant area for both flood management and providing resources for local communities (Jones, 2018).

References

1. Adhami, M., & Sadeghi, S. H. (2016). Sub-watershed prioritization based on sediment yield using game theory. Journal of Hydrology, 541, 977–987. https://doi.org/10.1016/j.jhydrol.2016.08.008
2. Arabameri, A., Pourghasemi, H. R., Blaschke, T., Pradhan, B., & Pradhan, B. (2020). Morphometric analysis for soil erosion susceptibility mapping using novel GIS-based ensemble model. Remote Sensing, 12(5), 874. https://doi.org/10.3390/rs12050874
3. Balasubramanian, A., Ramesh, K., & Sudhakar, S. (2023). Morphometric analysis of watershed using remote sensing and GIS for sustainable development. Remote Sensing Applications: Society and Environment, 29, 100970. https://doi.org/10.1016/j.rsase.2022.100970

 doi:10.20944/preprints202604.0560.v1

4. Bansode, S. S., Pawar, N. J., & Patil, K. N. (2022). GIS-based morphometric analysis for prioritization of micro-watersheds: A case study. Environmental Earth Sciences, 81(2), 46. https://doi.org/10.1007/s12665021-10152-z
5. Bharath, A., Kumar, K. S., Maddamsetty, R., Manjunatha, M., Tangadagi, R. B., & Preethi, S. (2021). Drainage morphometry based sub-watershed prioritization of Kalinadi basin using geospatial technology. Environmental Challenges, 5, 100277. https://doi.org/10.1016/j.envc.2021.100277
6. Borah, B., & Deka, R. (2020). Morphometric analysis and watershed prioritization using GIS in the Dudhnai river basin, Assam, India. Environmental Earth Sciences, 79(9), 2390. https://doi.org/10.1007/s12665-020-08838-1
7. Borrelli, P., Robinson, D. A., Fleischer, L. R., Lugato, E., Ballabio, C., Alewell, C., ... & Panagos, P. (2021). Soil erosion modelling: A global review and statistical analysis. Science of The Total Environment, 780, 146494. https://doi.org/10.1016/j.scitotenv.2021.146494
8. Carrasco, S. C. P., Ochiai, C., & Okazaki, K. (2016). Disaster induced resettlement: Multi-stakeholder interactions and decision making following tropical storm Washi in Cagayan de Oro, Philippines. Procedia Social and Behavioral Sciences, 218, 35–49. https://doi.org/10.1016/j.sbspro.2016.04.008
9. Cagayan de Oro City. (2013). Cagayan de Oro City Comprehensive Land Use Plan (CLUP) 2013–2022 (Vol. 1). Cagayan de Oro City Planning and Development Office.
10. Cagayan de Oro City Local Government Unit. (2023). Climate and Disaster Risk Assessment (CDRA) 2023. City Government of Cagayan de Oro.
11. Cagayan de Oro City Local Government Unit. (2022). Enhanced Local Climate Change Action Plan (ELCCAP) 2022-2031. City Government of Cagayan de Oro.
12. Cruz, R. V. O., Lasco, R. D., Pulhin, J. M., & Leavitt, S. M. (2020). Watersheds and climate resilience: Policy and practice in the Philippines. University of the Philippines Press.
13. Dhanush, S., Sundararajan, M., & Kumar, A. (2024). Quantitative morphometric analysis and prioritization of sub-watersheds for soil erosion susceptibility: A comparison between fuzzy AHP and compound parameter analysis methods. Environmental Monitoring and Assessment, 196(12), 788-804. https://doi.org/10.1007/s10661-024-08129-w
14. Department of Environment and Natural Resources. (2015). Integrated watershed management plan guidelines. Watershed Management Division, DENR.
15. Department of Environment and Natural Resources. (2021). Cagayan de Oro watershed characterization and vulnerability assessment report. DENR Region X.
16. De Luna, C. C., Calderon, M. M., Cruz, R. V. O., Tolentino, E. L., & Carandang, W. M. (2020). The economic value of Calliandra calothyrsus in watershed rehabilitation in Manolo Fortich, Bukidnon, Philippines. Journal of Environmental Science and Management, 76–84. https://doi.org/10.47125/jesam/2020_sp2/06
17. Dapin, I. G., & Ella, V. B. (2023). GIS-based soil erosion risk assessment in the watersheds of Bukidnon, Philippines using then RUSLE model. Sustainability, 15(4), 3325. https://doi.org/10.3390/su15043325
18. Eekhout, J. P. C., & de Vente, J. (2020). Assessing the effectiveness of sustainable land management for large-scale climate change adaptation. Science of The Total Environment, 718,137352. https://doi.org/10.1016/j.scitotenv.2020.137352
19. Food and Agriculture Organization of the United Nations. (2021). State of the world's land and water resources for food and agriculture: Systems at breaking point. FAO. https://doi.org/10.4060/cb9910en
20. Gela, H., & Mengistu, D. (2023). Watershed prioritization for conservation planning using RUSLE and morphometric methods: A case study of Gilgel Abay watershed, Ethiopia. Environmental Earth Sciences, 82(3),1821-1837. https://doi.org/10.1007/s12665-022-10398-9
21. Gomez, J. G. C. (2014). Urbanizing at the lake's edge: Watershed planning and governance lessons from the Laguna de Bay region, Philippines. Journal of Urban and Regional Planning, 1, 34–50. https://journals.upd.edu.ph/index.php/19May2014_surp/article/download/ 4206/3813
22. Horton, R. E. (1932). Drainage-basin characteristics. Eos, Transactions American Geophysical Union,13,350–361. https://doi.org/10.1029/TR013i001p00350

 doi:10.20944/preprints202604.0560.v1

23. Intergovernmental Panel on Climate Change. (2021). Climate change 2021: The physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. https://doi.org/10.1017/9781009157896
24. Jones, T. (2018). Flood control and river basins: A case study of the Cagayan de Oro River. Environmental Science Review, 22(1), 35-47.
25. E. D., & Garcia, L. B. (2019). Urbanization impacts on watershed hydrology: A case study of Cagayan de Oro. *Philippine Journal of Environmental Science, 25(2), 45–56.*
26. Marques, M. J., Schwilch, G., Bautista, S., & Stringer, L. C. (2022). Land degradation and restoration in socio-ecological systems: A systematic review of methods and tools. Science of The Total Environment, 806,150573. https://doi.org/10.1016/j.scitotenv.2021.150573
27. Marin, R. A., & Jamis, C. V. (2016). AES BIOFLUX Advances in Environmental Sciences - International Journal of the Bioflux Society.
28. NAMRIA. (2014). Informapper, 21. A publication on surveys, mapping, and resource information technology. National Mapping and Resource Information Authority. https://www.namria.gov.ph/
29. National Mapping and Resource Information Authority. (2018). *Topographic and hydrographic maps of Northern Mindanao.* NAMRIA.
30. Negash, D. A., Moisa, M. B., Merga, B. B., Sedeta, F., & Gemeda, D. O. (2021). Soil erosion risk assessment for prioritization of sub-watershed: The case of Chogo Watershed, Horo Guduru Wollega, Ethiopia. Environmental Earth Sciences, 80(17). https://doi.org/10.1007/s12665-021-09901-2
31. Pastor, I., Tanislav, D., Nedelea, A., Dunea, D., Serban, G., Haghighi, A. T., Sabau, D., & Bretcan, P. (2024). Morphometric analysis and prioritization of sub-watersheds located in heterogeneous geographical units—Case study: The Buzău River Basin. Sustainability, 16(17), 7567.https://doi.org/10.3390/su16177567
32. Prawiranegara, M. (2014). Spatial multi-criteria analysis (SMCA) for basin-wide flood risk assessment as a tool in improving spatial planning and urban resilience policy making: A case study of Marikina River Basin, Metro Manila – Philippines. Procedia - Social and Behavioral Sciences. https://doi.org/10.1016/j.sbspro.2014.07.319
33. Puno, G. R., & Marin, R. A. (2018). Flood simulation using geospatial models in Manupali Watershed, Bukidnon, Philippines. ResearchGate. https://www.researchgate.net/publication/327069663_Flood_simulation_using_geospatial_models_in_Manupali_Watershed_Bukidnon_Philippines
34. G., & Puno, R. (2019). Watershed conservation prioritization using geomorphometric and land use-land cover parameters. Global Journal of Environmental Science and Management, 5(3), 279–294. https://doi.org/10.22034/gjesm.2019.03.02
35. Puno, G., Villar, R. G., Toledo-Bruno, A. G., & Corpuz, O. (2015). GIS-based mapping and morphometric analysis of flood-prone sites in the three watersheds of Bukidnon. Social Science Research Network. https://doi.org/10.2139/ssrn.3530634
36. Rodeo, A. M. F., & Ambal, A. (2019). Socio-ecological resilience assessment: Initial findings and results in CALSANAG Balogo Sub-Watershed. ResearchGate. https://doi.org/10.13140/RG.2.2.23089.20327
37. Sahoo, S., Jha, M. K., & Panda, R. K. (2021). GIS-based morphometric analysis of a tropical river basin for erosion risk assessment. Environmental Monitoring and Assessment, 193, 754. https://doi.org/10.1007/s10661021-09545-2
38. Sharma, S., & Mahajan, A. K. (2020). GIS-based sub-watershed prioritization through morphometric analysis in the outer Himalayan region of India. Applied Water Science, 10(7). https://doi.org/10.1007/s13201-020-01243x
39. Singh, W. R., Barman, S. R., & Tirkey, G. (2021). Morphometric analysis and watershed prioritization in relation to soil erosion in Dudhnai Watershed. Applied Water Science, 11(9). https://doi.org/10.1007/s13201-021-014835
40. Smith, J., Lee, A., & Garcia, R. (2020). Watershed management in Cagayan de Oro: A study on hydrological impacts. Journal of Environmental Studies, 15(3), 102-114.
41. Strahler, A. (1957). Quantitative analysis of watershed geomorphology. Transactions, American Geophysical Union, 38, 913–920. https://doi.org/10.1029/TR038i006p00913

42. Talampas, W. D., & Cabahug, R. R. (2018). Morphotectonic characteristics of the Iponan River watershed in Cagayan de Oro City, Philippines. Mindanao Journal of Science and Technology, 16(1). https://mjst.ustp.edu.ph/index.php/mjst/article/download/147/98
43. Tesema, B. (2022). Integrated GIS and morphometric analysis for watershed prioritization in the Jigjiga watershed, Ethiopia. Geomatics, Natural Hazards and Risk, 13(1), 341-356. https://doi.org/10.1080/19475705.2022.2082476
44. Torrefranca, I. G., & Otadoy, R.E.S. (2022). GIS-based watershed characterization and morphometric analysis in Bohol Watersheds, Philippines. Geology, Ecology, and Landscapes, 1–12. https://doi.org/10.1080/24749508.2022.2158554
45. Tsioulou, A., Walker, J. F., Lo, D., & Yore, R. (2021). A method for determining the suitability of schools as evacuation shelters and aid distribution hubs following disasters: Case study from Cagayan de Oro, Philippines. Natural Hazards, 105(2), 1835–1859. https://doi.org/10.1007/s11069-020-04380-3