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Microgeomorphometric Analysis And Prioritization of Soil Erosion Vulnerable Sub-watersheds by Using Remote Sensing and GIS for Zuari River Basin, Goa, India

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Abstract Watershed prioritization for the identification of susceptible sub-basins for soil erosion in the Zuari river basin is carried out by using quantitative micro-geomorphometric analysis. The basin is divided into 10 sub-watersheds along with the stream order up to 7th order in Arc GIS software with the help of DEM data. Linear, areal, and relief parameters have been evaluated using Remote Sensing data and GIS techniques. Each parameter is examined independently as an indicator and appropriate rankings have been assigned by considering its role in soil erosion. Compound parameter values are calculated for all the sub-watersheds and the lowest compound value is allotted for the highest priority. Five priority levels are identified for the categorization of sub-watersheds, such as low, very low, moderate, high, and very high for conservation and planning of soil resource management. Three sub-watersheds scored very low compound value and hence are high priority basins which indicate the susceptible areas of intense soil erosion and need immediate action plans.

Keywords: *Morphometric analysis, remote sensing and GIS, Zuari River, watershed prioritization*

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1. Introduction

Sustainable development of natural resources is crucial to reduce the negative impacts of overutilization of resources on the environment and to ensure continued benefits for future generations. Human activities such as agriculture, deforestation, over-irrigation, mining, urbanization, and other construction projects have resulted in environmental degradation and resource depletion. Soil, like many other natural resources, is one of the most vital resources. Hence, conservation both in terms of quantity and quality based on scientific methods is a must. Soil erosion is a major problem related to land degradation in India. About 175 million ha of land in India, that is 53% of its total geographical area, is subjected to land degradation [1]. Therefore, appropriate planning and management of soil resources needs to be structured to avoid reckless utilisation of resources without proper vision.

A drainage basin is a fundamental natural unit taken into consideration for planning [11]. In the present research paper, the study area; the Zuari river basin, is divided into 10 sub-watersheds (Figure 2) and prioritized to identify the zones of intense soil erosion. Prioritization of sub-watersheds is an important aspect of watershed management in the Western Ghats section due to heavy surface flow of water and the potential for high soil erosion. The prioritization becomes important when the whole area is not feasible for the execution of conservation measures at once due to limited financial and human resources [14]. It is beneficial in identifying sensitive areas and the intensity of environmental problems where conservation measures should be employed on a priority basis [15].

2. Study Area

The study area lies in the Tiswadi, Sanguem, Ponda, Quepem, Salcete, and Mormugao regions of Goa state and covers 998 km^2 of area (Figure 1). The average elevation of the study region is 500 meters from the mean sea level. The river system flows through the dissected Western

Ghats in the east, the plateau region in the middle, and plain coastal areas in the west. The length of the main river channel is 69.91 km. Uguem, Panchamal, Guleli, Netorli, Cumbhari, Chirkanali, Kushavati, Gocoldem, Cavorem and Santana are the important tributaries of this river. The study region experiences a hot and humid tropical maritime climate. The study region completely falls on the windward side of the Western Ghats. The average temperature is 30^0c, which varies according to the seasons. The region receives an average of 300 cm of rainfall annually. The soils in the region are predominantly laterite, alluvial, and sandy. The eastern part of the study area has dense evergreen and semi-evergreen vegetation as it forms part of the Western Ghats. The important economic activities in the region are mining, agriculture, tourism, fishing, etc.

3. Data Source and Methodology

The study area is delineated with the help of SRTM DEM data and streams are digitized from the toposheet no. 48E/15, 48I/3, 48I/7, 48I/4, and 48I/8 at 1:50000 scale. GIS techniques are adopted for the data analysis in the present study. The data is processed using Arc GIS software. The Strahler's stream ordering method is used for stream order patterns. Linear, areal, and relief parameters such as stream order, stream length, bifurcation ratio, drainage density, stream frequency, elongation ratio, form factor, drainage texture, constant channel maintenance, length of overland flow, relief ratio, dissection index, ruggedness index, relative relief, and stream gradient are evaluated with the help of formulae suggested by Horton [2], Strahler [10], and Schumn [3]. Each of the parameters is ranked based on the score. Prioritization of all sub-watersheds is carried out by calculating compound parameter values. The watershed with the lowest compound value is given the highest priority and the final map of prioritization is prepared.

4. Result and Discussion

The Zuari River basin with its drainage network is shown in Figure 1. The morphometric parameters are classified as linear, relief, and areal factors. The evaluated morphometric parameters are taken to understand the direct and/or indirect influence on the intensity and amount of soil erosion. Table 1 shows the various methods employed in this paper, and Table 2 shows the results arrived at of various components applied for the evaluation of the problem under study.

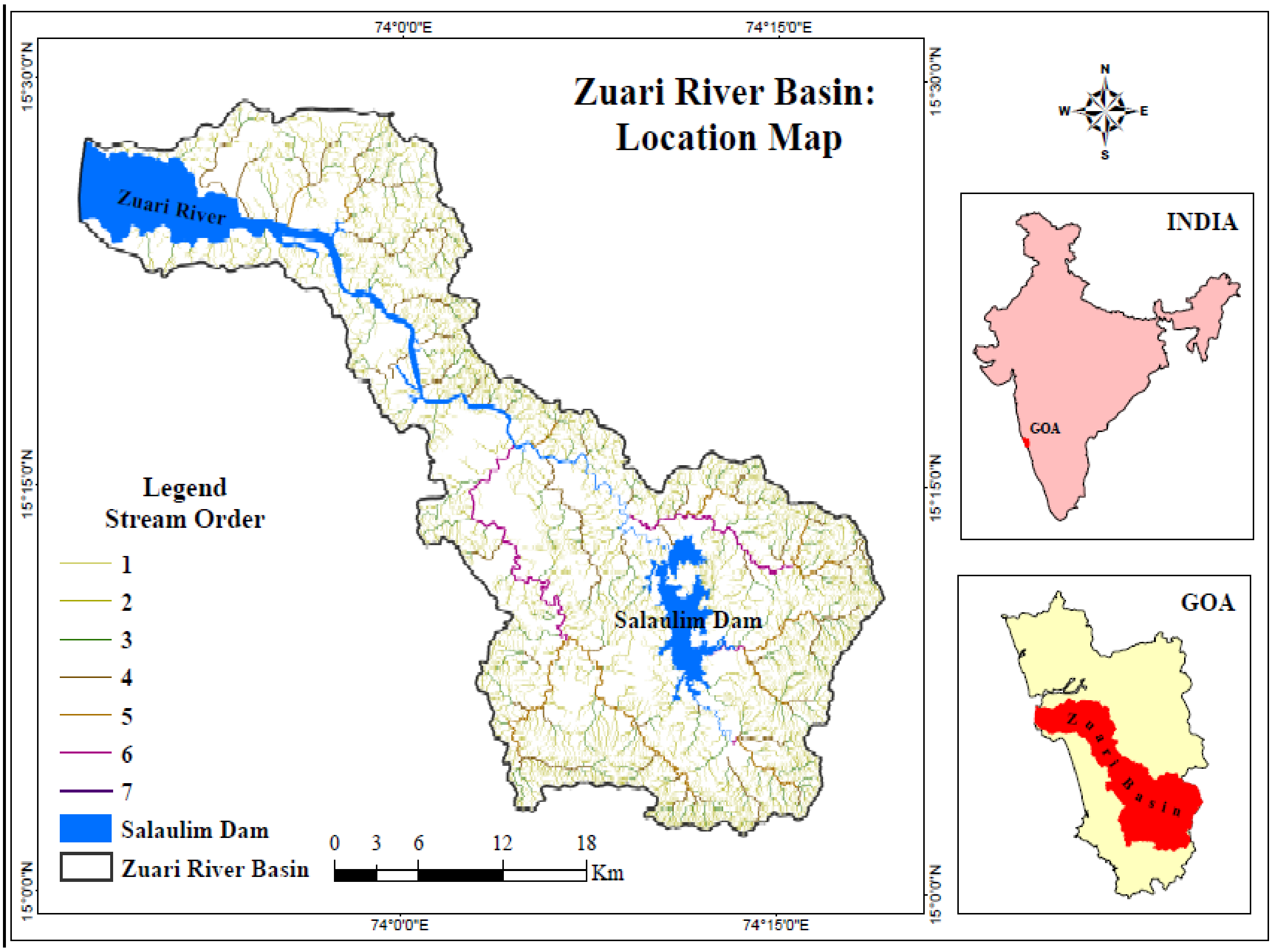

Figure 1. Location Map

Table 1. METHODS OF CALCULATING MORPHOMETRIC ATTRIBUTES

MORPHOMETRIC ATTRIBUTES	METHOD	AUTHOR
Stream order (u)	Hierarchical arrangement	Strahler (1952) [10]
Bifurcation ratio (Rb)	Rb= Nu/Nu+1 Wherein, Rb= Bifurcation ratio, Nu= Number of streams in a given order, Nu+1= Number of streams in next higher order	Schumn, 1956 [3]
Drainage density (Dd)	Dd= ∑L/A Wherein, ∑L= total length of all streams, A= area of the basin	Horton (1945) [2]
Stream frequency (Fs)	Fs= ∑N/A Wherein, Fs= stream frequency, ∑N= total number of streams, A= area of the basin	Horton (1945) [2]
Drainage texture (Dt)	Dt= N1/P Wherein, Dt= drainage density, N1= Number of first order streams, P= perimeter	Horton (1945) [2]
Elongation ratio (Re)	$Re=2\sqrt{A/\pi}$ /Lb Wherein, Re=elongation ratio, A=area of basin, π= 3.14, Lb= length of the basin	Schumn 1956 [3]
Circularity ratio (Rc)	$Rc= 4\ \pi\ A/p^2$ Wherein, Rc= circulatory ratio, π= 3.14, A= area of the basin, p= perimeter of basin	Miller, 1953 [4]
Form factor (Ff)	$Ff=A/Lb^2$ Wherein, Ff= form factor, A= area of the basin, Lb= length of basin	Horton (1945) [2]
Length of overland flow (Lf)	Lf= 1/2Dd Wherein, Lof= length of overland flow, Dd= drainage density	Horton (1945) [2]
Relative relief	Maximum elevation- Minimum elevation	Schumn, 1956 [3]
Relief ratio	Rr= Rh/Lb Wherein, Rr= relief ratio, Rh= basin relief, Lb=length of the basin	Strahler (1952) [10]
Ruggedness index (Rn)	Rn= Rh*Dd/1000 Wherein, Rn= ruggudness index, Rh=basin relief, Dd= drainage density,	Schumn, 1956 [3]

Source: Literature review.

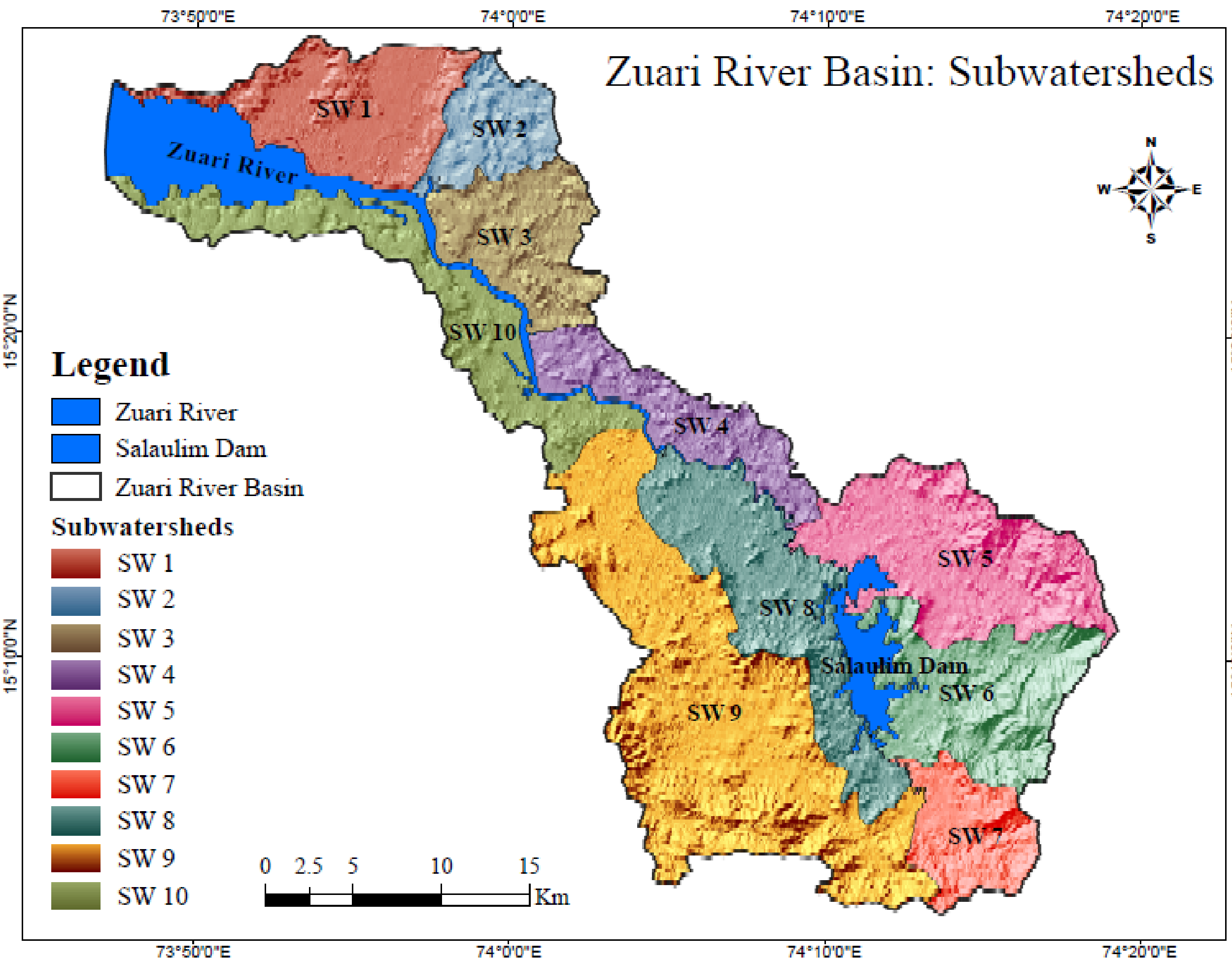

Figure 2. Zuari River Sub watersheds

Table 2. MORPHOMETRIC ASPECTS

Sub watersheds	1	2	3	4	5	6	7	8	9	10	Zuari Basin
Bifurcation ratio (Rb)	3.74	4.27	5.36	5.18	3.83	3.73	3.5	3.91	4.43	7.24	4.14
Drainage density (Dd)	1.93	3.57	3.91	4.57	3.98	3.98	4.66	2.70	3.34	2.33	3.20
Stream frequency (Fs)	3.23	7.92	8.75	12.47	8.81	8.29	11.85	5.03	6.53	3.87	6.59
Drainage texture (Dt)	3.46	7.24	9.98	9.80	12.28	10.23	10.94	4.92	10.53	2.28	22.37
Elongation ratio (Re)	0.49	0.73	0.76	0.43	0.62	0.77	0.71	0.48	0.54	0.30	0.52
Circularity ratio (Rc)	0.32	0.44	0.43	0.23	0.36	0.34	0.42	0.20	0.23	0.08	0.25
Form factor (Ff)	0.19	0.42	0.42	0.14	0.30	0.47	0.40	0.16	0.23	0.07	0.21
Length of overland flow (Lf)	0.25	0.14	0.13	0.10	0.12	0.12	0.12	0.18	0.14	0.21	0.15
Relative relief	290	288	404	215	865	864	832	433	831	170	885
Relief ratio	0.03	0.03	0.04	0.05	0.05	0.06	0.11	0.03	0.02	0.05	0.01
Ruggedness index (Rn)	0.55	1.02	1.57	0.98	3.44	3.43	3.87	1.16	2.77	0.39	2.83

Source: estimated by researcher.

4.1. Stream Order

Stream order is the hierarchical pattern of all streams in the river basin [5]. In the present study, stream ordering is given based on Strahler's method, wherein small unbranched streams are first-order streams. When first-order streams merge to form second-order streams, when two second-order streams unite to form third-order streams, and so on. A larger area has a higher order of streams. The stream orders in the sub watersheds vary between 4th up to 7th order. Sub-watersheds portray the variation in their stage of growth. Stream order from 1 to 7 is identified in the study area according to Strahler's stream ordering system.

4.2. Stream Length

Stream length depicts the hydrological properties of the drainage bedrock that determines surface runoff [5]. A longer stream length reveals a gentle slope, and a shorter stream length indicates a steeper slope [8].

Stream length for the study area varies from 3 km to 1827.85 km for all sub-watersheds, which shows topographic variations in the region. Stream length of first order is 1827.85 km (57.70%), second-order 629.26 km (19.86%), third-order 337.67 km (10.65%) 173.41 km (5.47%), 78.24 km (2.46%), 51.42 km (1.62%), and 69.91 km (2.20%) for fourth, fifth, sixth and seventh order respectively.

4.3. Bifurcation Ratio

The bifurcation ratio is the number of streams in the given order to the number of streams in the next higher order that indicates the ruggedness of the region [2]. It is influenced by properties of bedrock characteristics, drainage density, area, and shape of the basin [9]. Bifurcation values ranging from 3 to 5 indicate the lesser influence of structural features on drainage patterns [10]. The constant bifurcation ratio represents the homogenous characteristics of the topography in the basin [5]. A high bifurcation ratio indicates a greater degree of dissection and structural disturbances, which contribute to the higher extent of soil erosion [17]. The mean bifurcation ratio of the Zuari basin is 4.14 with minor variations in all orders. The values of the bifurcation ratio range from 3.50 in SW7 and 7.24 in SW10. A higher bifurcation ratio in SW10 is due to a decline in the number of streams from lower order to higher order and the influence of structural control.

4.4. Drainage Density

Drainage density refers to the ratio between the total length of the streams and the total area in the basin [2]. It can also be defined as the mean length of a stream segment per unit area [9]. Drainage density is influenced by the properties of bedrock, rainfall, relief, vegetation, amount of river load, and volume of water. It is high in humid areas due to high rainfall and soft rock, but less in dry areas due to less rainfall and the low permeability of hard rock [9]. Drainage density and soil erosion are directly proportional to each other [13]. The drainage density of the Zuari River is 3.20 km/km^2; however, there is variation in its sub-watersheds. It ranges from 1.93 km/km^2 in SW1 to 4.6 km/km^2 in SW7. SW1, SW8, and SW10 score less than the basins' average value, which indicates a relatively younger basin. The rest of the sub-basins score more than the average that show dissected and mature river basins.

4.5. Stream Frequency

Stream frequency is the total number of streams per unit area [2]. It is computed by dividing the total number of streams in the basin by the total area of the basin [12]. It is influenced by lithological characteristics, vegetation, and rainfall. High stream frequency designates soft rock and more humidity that contributes to the intensity of the soil erosion, whereas, low stream frequency shows hard rock and low humidity where the potency of the erosion is comparatively less [9]. The stream frequency of the entire basin is 6.59. The values of stream frequencies for all sub-watersheds are calculated, categorized, and shown in the Table 2.

4.6. Drainage Texture

Drainage texture refers to the spacing of stream segments in the basin and it can be fine, coarse, and medium [5]. It reflects the lithology, permeability of the rock, and relief [6]. Higher drainage texture indicates more soil erosion [18]. The drainage texture of the entire basin is 22.37, which represents the moderate drainage texture category.

4.7. Length of Overland Flow

The length of overland flow is the flow of water on the land surface before it is concentrated in the first-order streams of the basin [2]. The flow is greater when the rocks are impermeable, and in highly dissected areas the flow is less. This represents the youth stage of the river, with more potential for soil erosion. The low value for the entire basin is 0.15. That represents less runoff and the lower potential of the region to erode the soil.

4.8. Relative Relief

Relative relief, also referred to as local relief, is the difference between the highest and lowest elevation in the basin [3]. High relative relief signifies dissected areas, more runoff, and the greater potential of the region to erode soils [9]. The relative relief of the Zuari basin is 885 meters, which can be considered as high, and it decreases in a varying manner from east to west towards the coastal areas of the Arabian Sea.

4.9. Relief Ratio

The relief ratio is the ratio between total basin relief (relative relief) and basin length (the highest dimension of the basin parallel to the main river) [3]. It assists in analysing the steepness of the slope of the basin and its potentiality to erode the land [16]. Higher relief ratios have more potential for soil erosion. In the present study, the relief ratio is 0.01 for the entire basin and it indicates that the mean relief and basin length are inversely increasing.

4.10. Ruggedness Index

It is the measure of the intensity of dissection of the basin [10]. A high Rn value represents more intense soil erosion [7]. The ruggedness index of the Zuari river basin is 2.83 and it can be categorised as moderately dissected, although a few sub-basins in the Western Ghats score Rn values higher than the basin's average value, indicating a high degree of dissection, steep slopes, and narrow valleys resulting in more potential for erosion.

4.11. Elongation Ratio

The elongation ratio was defined by Schumm [3] as the ratio of the diameter of a circle in the same area as the drainage basin to the maximum length of the basin. Its values range from 0 to 1 and can be categorized as elongated, oval and circular [3]. A value close to 1 represents the circular shape of the basin with low relief and a value close to 0 indicates the elongated shape of the basin with a steep slope [3]. It is influenced by the geological characteristics of the basin. There is an indirect relationship between elongation ratio and soil erosion. The elongation ratio of the Zuari basin is 0.52, which indicates the elongated shape of the basin.

4.12. Circularity Ratio

It is the ratio of the area of the basin to the area of the circle having the same circumference as the perimeter of the basin [4]. It is influenced by rainfall, land use cover, and lithology of the basin [9]. The basin is homogenous and circular when the circularity ratio is close to 1 with geological uniformity and the irregularity of the basin increases as the value decreases. Higher circularity values indicate a lesser amount of soil erosion. The circularity ratio of the entire basin is 0.25 and it indicates the highly irregular shape of the basin.

4.13. Form Factor

Form factors provide support for the shape analysis. A higher value of Ff designates wider basins that have relatively lesser scope for soil erosion and lower values specify narrow and elongated drainage basins with more soil erosion potentiality [2]. The Ff for the Zuari river basin is 0.21, which indicates a linear, younger, and relatively narrow basin.

4.14. Prioritization of Sub-watersheds in Zuari Basin

Morphometric parameters, also referred to as erosion risk assessment parameters, are used for the prioritization of sub-watersheds as they directly influence the amount and intensity of soil erosion. Higher values of linear and relief parameters indicate more soil erosion and lower values depict lesser soil erosion. These higher values of linear and relief parameters are ranked as 1. There is an inverse relation between shape parameters and soil erosion; that is, higher values of shape parameters indicate lower soil erosion, and hence the lower value is ranked as 1 (Table 3). The compound parameter is calculated based on rankings of the morphometric parameters, and a lower compound value has been given the highest priority, and vice versa. For effective management of resource conservation, prioritization is very essential to control and minimise the effects of natural calamities. In the present study, morphometric parameters are evaluated for ten sub-watersheds of the Zuari river basin and basins are categorized into five priority levels, such as low, very low, moderate, high, and very high.

4.15. Very High Priority

Low compound value is scored by sub-watersheds SW4, SW5, and SW7 in the entire Zuari basin, which represent sub-basins of higher soil erosion (Figure 3). Soil erosion is very high in these sub-basins due to the topographic characteristics of the region. These sub-basins are located in the high elevated areas of the Western Ghats with maximum potential energy to erode the sediments with the flow of water. Other influencing factors are a greater number of tributaries, steep slopes, and deep valleys. These regions also receive rainfall of more than 300 cm annually that increases the amount and velocity of water due to steeper slopes. Considering these factors, the aforesaid sub-basins should get priority for the conservation of soil resources.

4.16. High Priority

Sub-watershed SW9 and SW10 are categorized into high priority zones. These basins have similar geographic characteristics mentioned for the sub-watersheds of very high priority. These basins are narrow and elongated with moderate slopes and varying geological properties. These sub-basins also require a high degree of priority concerning the conservation of soil.

4.17. Moderate Priority

Sub-watershed SW8 and SW6 are categorized as moderate priority zones. Although these sub-basins are a part of the Western Ghats and highly dissected and should fall under a high priority zone, due to differences in other morphological properties, the compound value has increased as compared to the above-mentioned sub-basins.

4.18. Low and Very Low Priority

In this category, we have sub-watersheds such as SW2, SW1, and SW3. These sub-basins have moderate to low elevation and are relatively broader and compact. Other reasons for less soil erosion in these basins are gentle slope gradients and rainfall of less than 250 cm in a year.

Table 3. PRIORITIZATION OF SUB WATERSHEDS BY USING MORPHOMETRIC PARAMETERS

Sub-watershed	Rb	Dd	Fs	Dt	Lf	Rr	Rh	Rn	Re	Rc	Ff	Sum	Cp	Rank	Assessed Priority
SW1	8	10	10	9	1	7	8	9	4	5	4	75	6.81	9	Very low
SW2	5	6	6	7	4	8	7	7	8	10	8	76	6.90	10	Very Low
SW3	2	5	4	5	6	6	6	5	9	9	9	66	6	8	Low
SW4	3	1	1	6	10	9	4	8	2	4	2	50	4.54	2	Very High
SW5	7	4	3	1	8	1	3	2	6	7	6	48	4.36	1	Very High
SW6	9	3	5	4	7	2	2	3	10	6	10	61	5.54	7	Moderate
SW7	10	2	2	2	9	3	1	1	7	8	7	52	4.72	3	Very High
SW8	6	8	8	8	3	5	9	6	3	2	3	61	5.54	6	Moderate
SW9	4	7	7	3	5	4	10	4	5	3	5	57	5.18	4	High
SW10	1	9	9	10	2	10	5	10	1	1	1	59	5.36	5	High

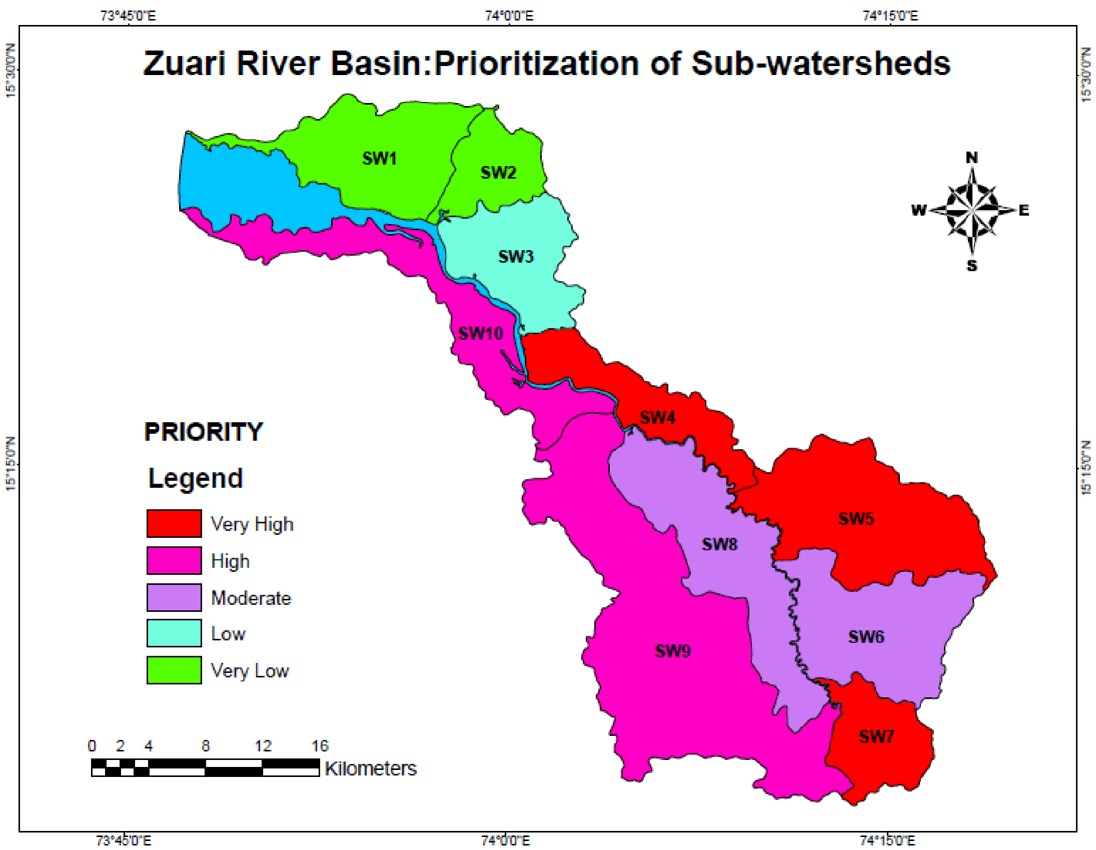

Figure 3. Prioritization of Sub watersheds of Zuari River Basin

5. Conclusion

Watershed prioritization is an essential element of planning, management, and conservation of resources.

In the present study, linear, relief, and shape parameters are evaluated for ten sub-watersheds of the Zuari basin in remote sensing and GIS environments.

The parameters are further processed to get the compound values to rank the sub-watersheds based on their priority for soil erosion management. From the research, it is clear that sub-watershed SW4, SW5, SW7 SW9, and SW10 need the immediate attention of the government to take necessary action for the conservation of soil resources.

These sub-watersheds are facing more erosion due to heavy rainfall, steep slopes, more tributaries, and other geological properties.

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