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Spatial Analysis Software For Morphometric Studies To Sub-Watershed Level Prioritization Of Talpona River In Goa, India

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Abstract

This study delves into the Talpona River located in Canacona taluka of Goa, encompassing an area of 183.024 sq. km and boasting a perimeter of 77 km. Positioned at 14°59’14” N latitude and 74°2’40” E longitude in the Talpona area of Canacona taluka, South Goa, the river is characterized by 2162 streams and a basin length of 31.67 km. The study area features rich soil cover, dense vegetation, and substantial annual rainfall, ensuring soil moisture retention for the majority of the year. For prioritization based on morphometric analysis utilizing GIS and remote sensing techniques, the study area is subdivided into 11 sub-watersheds (TSB-1 to TSB-11). The drainage density of sub-watersheds ranges from 3.49 to 7.19, with an elongation ratio varying from 0.44 to 0.75, indicating high relief and steep ground slopes. This variability is attributed to diverse slope, relief, and structural conditions within the sub-watershed. Calculation of compound parameter values is conducted, and the sub-watershed with the lowest compound parameter is accorded the highest priority. In this investigation, TSB-1, TSB-2, and TSB-7 are assigned the highest priority due to their elevated position and increased runoff. This prioritization serves as a valuable guide for efficient watershed management and conservation initiatives in the Talpona River region.

Key word: Talpona, Prioritization, watershed and Morphometric

Introduction

A watershed is defined as the land area drained by a river and its tributaries, serving as the boundary for surface water drainage. The integration of GIS (Geographic Information System) and

Remote Sensing is widely acknowledged as a unique, highly effective, and versatile technology for evaluating, managing, and monitoring natural resources and the environment. The study of the Talpona basin is centered on remote sensing and GIS techniques, aiming to enhance water resource management and related activities. This approach contributes to improving the livelihoods of people residing in the watershed area while ensuring ecosystem preservation. Additionally, the land-use and land-cover map of the Talpona area serves as a foundational resource for sustainable management. Morphometric analysis of the basin enables the examination of drainage development, surface run-off, infiltration capacity, and groundwater potential. The use of GIS and remote sensing techniques, including satellite imagery, facilitates morphometric analyses of the drainage basin. The results obtained from prioritizing the basin can be instrumental in implementing development and management programs. A similar study conducted by Mishra Sangita S. et al. (2010) focused on the morphometric analysis and prioritization of the Hati River watershed in Odisha, showcasing the utility of GIS in such analyses. In another study, Pisalet al. explored the morphometric analysis of the Bhogavati River Basin in Kolhapur District, Maharashtra. This current study follows suit by conducting morphometric analysis and prioritization of sub-watersheds within the Talpona watershed in Canacona taluka of South Goa district, India. The research aims to contribute valuable insights for effective watershed management and conservation efforts in the region.

STUDY AREA

Situated on the shores of the Arabian Sea within Canacona taluka, Talpona is a quaint fishing village in the South Goa District. The Talpona River is positioned at 14°59'14"N latitude and 74°2'40"E longitude in the Talpona area of Canacona taluka in South Goa. The study area is characterized by rich soil cover, dense vegetation, annual rainfall, and consistent soil moisture throughout most of the year. Falling within a tropical wet, humid, and dry climatic region, the mean monthly temperature ranges from 25-33 °C. The annual precipitation recorded in this area is 2994 mm, with variability between monsoon and non-monsoon seasons leading to a short dry season in certain parts of the watershed.

The study area is covered by Survey of India (SOI) toposheets numbered 48/I/4/SW, 48/I/4/SE, 48/J/4/NE, 48/J/4/NW, all on a 1:25,000 scale. These toposheets provide detailed cartographic representations of the region, aiding in various geographical and environmental studies within the Talpona area.

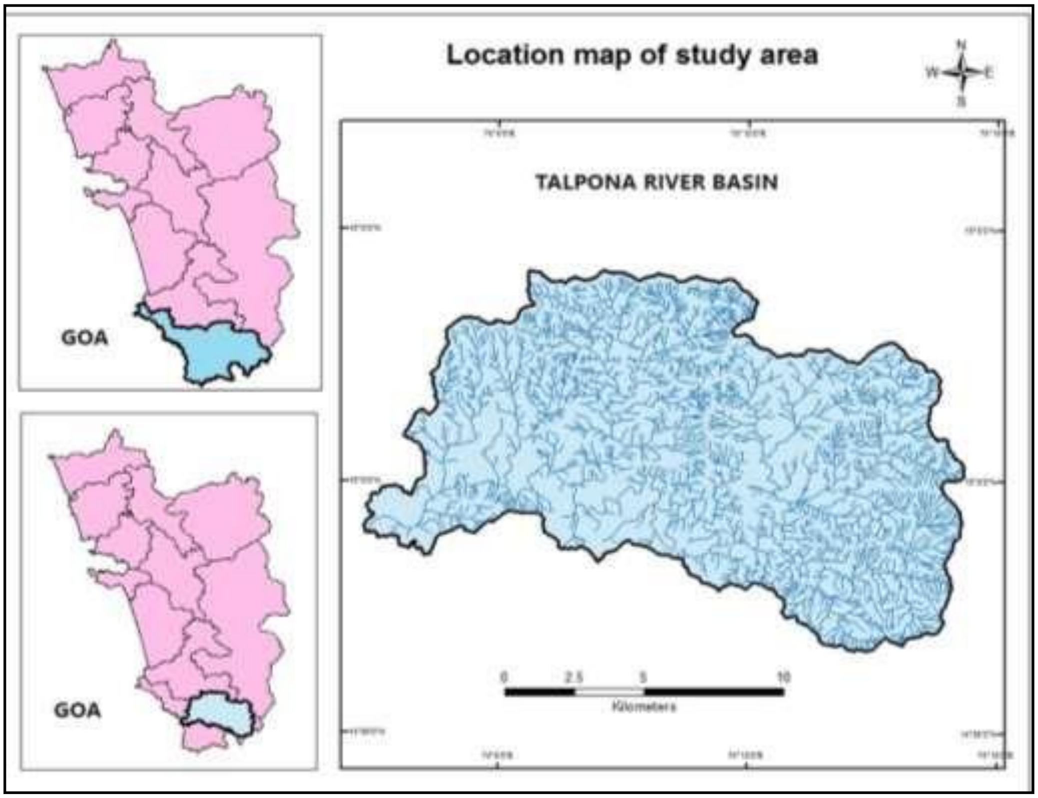

Fig.1: Location Map of Study Area

Data and Methodology

The majority of the work is based on secondary data, primarily sourced from ASTER, Carto DEM, and LANDSAT-8 satellite data, along with the Survey of India (SOI) toposheet index numbers 48/I/4/SW, 48/I/4/SE, 48/J/4/NE, and 48/J/4/NW. The toposheets were scanned and then both the toposheets and satellite images were mosaiced. Subsequently, the mosaiced images were georeferenced using latitudes and longitudes, with projections assigned as WGS 1984 datum in the 43 North zone. Digitization was carried out using ArcGIS software, involving the creation of a geodatabase file with a feature dataset and feature class. Manual digitization was performed for the basin boundary, streams, etc. Stream ordering was determined using Strahler's method (Strahler, 1964), and topology was created to rectify digitization errors. The basin was manually demarcated using the ridge line. ArcGIS hydrology tools were applied to the satellite data, starting with the fill tool to fill gaps in the image, followed by the flow direction tool to ascertain flow direction in the basin. The flow accumulation tool was then employed to determine accumulation within the basin, automatically demarcating the basin. Stream ordering was performed using Strahler's method. Morphometric analysis, inspired by the work of Mishra Sangita S. et al. (2010), utilized formulas from Horton (1945), Strahler (1964), Schumm (1956), Nookaratnam et al. (2005), and Miller (1953) for calculating morphometric parameters. Manjare et al. (2014) and Narendra Kumar (2013) have also conducted morphometric analyses in different river basins, showcasing the utility of GIS and remote sensing. In the present study, morphometric analysis and prioritization ratings for all eleven sub-watersheds of the Talpona watershed were determined by calculating compound parameter values. The sub-watershed with the lowest compound parameter value received the highest priority in the prioritization process.

Result and Discussion

Talpona watershed is divided into eleven sub – watersheds with codes TSB-1 to TSB-11.

- **Linear aspect**

1. Stream Order (U): The Talpona River exhibits seven stream orders, featuring a network of 2162 streams that collectively span an area of 183.024 sq. Km.

2. Stream Number (Nu): The stream number (Nu) is defined as the total count of stream segments within each order. The Talpona River basin has been categorized into seven stream orders. The stream numbers for both the entire basin and its individual sub-watersheds are outlined in Table 1.

Table 1 Stream analysis

Sub-watersheds	Stream number (Nu) of different orders (U)								Basin length Lb (Km)	Stream frequency(Fs)
	1	2	3	4	5	6	7	Total		
TSB-1	148	33	15	3	1	-	-	200	6.04	13.44
TSB-2	181	40	10	2	1	-	-	234	6.5	15.21
TSB-3	106	32	9	2	2	1	-	152	5.51	11.11
TSB-4	144	34	8	2	1	1	-	190	8.12	14.49
TSB-5	116	35	8	2	1	-	-	162	6.38	9.67
TSB-6	151	37	8	2	-	1	-	199	9.99	9.82
TSB-7	255	61	12	3	1	-	-	332	6.59	17.46
TSB-8	84	22	7	1	-	2	1	117	7.71	7.92
TSB-9	198	45	9	2	2	1	-	257	8.1	15.92
TSB-10	140	34	9	2	1	-	1	187	7.3	10.15
TSB-11	111	26	5	1	-	-	1	144	11.34	7.07

3. Basin Length (Lb): The Talpona River exhibits a basin length of 31.67 km. Sub-watersheds within the Talpona River basin have varying basin lengths, with TSB-11 having the longest length (11.34 km), followed by TSB-6 (9.99 km). TSB-1 has the shortest basin length at 6.04 km (see Table 1).

4. Stream Frequency (Fs): Defined by Horton (1945) as the number of stream segments per unit area, stream frequency is an important parameter. The stream frequencies for all sub-watersheds are detailed in Table 1. The study indicates that sub-watersheds with extensive forest cover exhibit lower drainage frequency, while those with more agricultural land show higher drainage frequency. Notably, TSB-7 (17.46) and TSB-9 (15.92) display higher drainage frequencies, suggesting increased runoff compared to others. Conversely, TSB-11 exhibits a lower drainage frequency at 7.07.

5. Stream Length (Lu): Stream length, as per Horton's definition (1945), represents the total length of individual stream segments for each order. The stream lengths were calculated for the entire basin and its 11 sub-watersheds (refer to Table 2). The results reveal a decrease in the total length of stream segments as the stream order increases. Table 2 illustrates the stream length ratios for the sub-watersheds.

Table 2 Order wise stream length of sub-watersheds

Sub-watershed	**Order wise stream length (Lu) meters**								**Stream length ratio**					
	1	**2**	**3**	**4**	**5**	**6**	**7**	**Total**	2/1	3/2	4/3	5/4	6/5	7/6
TSB-1	54415.19	17943.84	11361.82	2203.78	8607.59	-	-	94533.04	0.32	0.63	0.19	3.90	-	-
TSB-2	54515.81	15566.33	8201.16	6182.06	5093.70	-	-	89559.09	0.28	0.52	0.75	0.82	-	-
TSB-3	32088.47	14458.42	7426.60	5051.57	8617.16	17293	-	84935.26	0.45	0.51	0.68	1.70	1.99	-
TSB-4	40919.83	13157.50	9473.06	3020	8607.59	17293	-	94271.01	0.32	0.71	0.31	2.84	2	-
TSB-5	35914.38	14196.30	6883.67	6994.29	3523.45	-	-	67512.11	0.39	0.48	1.01	0.50	-	-
TSB-6	44022.49	26506.48	7663.51	2298.46	-	17293	-	97783.96	0.60	0.28	0.29	-	-	-
TSB-7	73015.33	17393.10	12323.17	7146.76	3546.38	-	-	113424.77	0.23	0.70	0.57	0.49	-	-

TSB-8	29.757.05	9417.53	3867.94	1847.77	-	24839.16	11086.20	80815.67	0.31	0.41	0.47	-	-	0.44
TSB-9	49199.73	16456.14	11371.89	2226.65	6157.29	7546.16	-	92957.88	0.33	0.69	0.19	2.72	1.22	-
TSB-10	40982.09	15630.08	5690.61	4128.60	2323.27	-	11086.20	79840.86	0.38	0.36	0.26	0.56	-	-
TSB-11	35639.51	9790.77	10011.54	4574.89	-	-	11086.20	71102.92	0.27	1.02	0.45	-	-	-

6. Bifurcation Ratio (Rb): The Bifurcation Ratio (Rb) is defined as the ratio of the number of stream segments of a given order to the number of segments of the next higher order (Schumm S. A., 1956). In general, higher elevations tend to exhibit higher bifurcation ratios, and vice versa. This is because higher elevations often have more 1st order streams, which then confluence to form streams of the next higher order. The bifurcation ratios for the Talpona sub-watersheds are provided in Table 3. Notably, TSB-7 stands out with the highest bifurcation ratio at 3.56. This is attributed to TSB-7's higher elevation, resulting in a greater number of 1st order streams that confluence to form 2nd order streams and so forth. Conversely, TSB-3 displays the lowest bifurcation ratio at 2.56. This is due to its location on a gentle slope, resulting in fewer 1st order streams and, consequently, a lower bifurcation ratio. Higher bifurcation ratios generally indicate increased water flow.

Table 3 Bifurcation ratio of sub-watersheds

Sub-watersheds	**Bifurcation ratio (Rb)**							
	1	2	3	4	5	6	7	Mean
TSB-1	4.48	2.2	5	3	1	-	-	3.13
TSB-2	4.5	4	5	2	1	-	-	3.3
TSB-3	3.31	3.55	4.5	1	2	1	-	2.56
TSB-4	4.23	4.25	4	2	1	1	-	2.74
TSB-5	3.31	4.37	4	2	1	-	-	2.93
TSB-6	4.08	4.62	4	2	-	1	-	3.14
TSB-7	4.18	5.08	4	1	-	-	-	3.56
TSB-8	3.81	3.14	7	1	-	2	1	2.99
TSB-9	4.4	5	4.5	0	2	1	-	3.38
TSB-10	4.11	3.77	4.5	1	1	-	1	2.87

TSB-11	4.26	5.2	5	1	-	-	1	3.29

- **Aerial Aspect (Shape Parameters)**

1. **Basin Area (A):** Talpona River has a basin area of 183.024 sq. Km. The specific areas for the sub-watersheds has been detailed in Table 4.
2. **Basin Perimeter (P):** Basin perimeter denotes the outer boundary of the watershed enclosing its area. Talpona River has a perimeter of 77Km, with the specific perimeters for the sub-watersheds outlined in Table 4.
3. **Form Factor (Ff):** Form factor, the ratio of basin area to the square of the basin length, is calculated for all sub-watersheds and ranges from 0.15 to 0.45 (refer to Table 4). The observed values suggest that the sub-watersheds are generally elongated, with higher Ff values indicating increased elongation. A higher Ff signifies basins with high peaks and shorter flood durations, generally making flood flows more manageable.
4. **Elongation Ratio (Re):** The elongation ratio is defined as the ratio of the diameter of a circle with the same area as the basin to the maximum basin length. Values for the elongation ratio range from 0.44 to 0.75 for the sub-watersheds (see Table 4). TSB-11 stands out as more elongated, while TSB-1, TSB-2, TSB-4, TSB-6, TSB-8, TSB-9, and TSB-10 are classified as elongated. TSB-3, TSB-5, and TSB-7 are considered less elongated.
5. **Circularity Ratio (Rc):** Circularity ratio, representing the ratio of watershed area to the area of a circle with the same perimeter, varies from 0.30 to 0.66 across the sub-watersheds (see Table 4). Higher values of circularity ratio, such as that of TSB-5 (0.66), indicate a relatively more circular shape. Steep slopes, high relief, and specific structural conditions contribute to the distinctive circularity ratio of TSB-5.
6. **Compactness Coefficient (Cc):** Compactness coefficients are outlined in Table 4, ranging from 1.20 to 1.82 across the sub-watersheds. TSB-5 exhibits the lowest value at 1.20, while TSB-11 has the highest value at 1.82. The compactness percentage, calculated for each sub-watershed, suggests that TSB-11 is comparatively more compact, representing 11.57% compactness

Table 4 Areal aspects of sub-watersheds

Sub-watersheds	Area (sq. Km)	Perimeter (Km)	Ff	Re	Rc	Cc	Cc (%)	Dd	T
TSB-1	14.88	17.75	0.4	0.7	0.59	1.3	8.26	6.35	11.26
TSB-2	15.38	17.8	0.36	0.68	0.6	1.28	8.14	5.8	13.14
TSB-3	13.77	18.34	0.45	0.75	0.51	1.39	8.84	6.16	8.34
TSB-4	13.11	19.43	0.19	0.5	0.43	1.51	9.60	7.19	9.77
TSB-5	16.75	17.77	0.41	0.72	0.66	1.22	7.76	4.03	9.11
TSB-6	20.46	22.96	0.2	0.57	0.48	1.43	9.09	4.77	8.75

TSB-7	19.01	19.73	0.43	0.74	0.61	1.27	8.07	5.96	16.82
TSB-8	14.72	21.3	0.25	0.56	0.4	1.56	9.92	5.49	5.49
TSB-9	16.14	23.57	0.24	0.55	0.37	1.65	10.49	5.75	10.9
TSB-10	18.41	19.82	0.34	0.62	0.58	1.3	8.26	4.33	9.43
TSB-11	20.34	29.08	0.15	0.44	0.3	1.82	11.57	3.49	4.95

7.**Drainage Density (Dd):** Drainage density, defined as the stream length per unit area in the region of the watershed (Horton, 1945), varies across the sub-watersheds, ranging from 3.49 to 7.19 (refer to Table 4). TSB-11 exhibits the lowest drainage density (3.49), indicating highly resistant, impermeable subsoil material with dense vegetative cover and low relief. Conversely, TSB-4 shows the highest drainage density (7.19), suggesting weak or impermeable surface material, less vegetation, and high relief.

8. **Drainage Texture (Dt):** Drainage texture, representing the total number of stream segments of all orders per perimeter of the area (Horton, 1945), is classified into five categories: very coarse (<2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8), and very fine (>8). Talpona River basin's drainage texture varies from 4.95 to 16.82 (see Table 4). Most sub-watersheds exhibit a texture ranging from moderate to very fine. A fine texture implies low percolating capacity due to smaller particle size, resulting in low infiltration capacity. TSB-2 and TSB-7, being highly elevated areas with steep slopes and very high drainage density (13.14 and 16.82, respectively), indicate increased surface runoff. TSB-11, with the lowest drainage texture at 4.95, suggests higher infiltration capacity and a gentle slope

- **Relief Aspect**

1. **Basin Relief (H):** Basin Relief: Basin relief is defined as the elevation difference between the highest and lowest points of the valley floor. For Talpona basin, the highest relief value is 863, and the lowest relief value is 3, resulting in a total relief of 860. Specific relief values for each sub-watershed are detailed in the provided table.

Table 6 Relief ratio of sub-watersheds

Sub- watersheds	**Highest relief (m)**	**Lowest relief (m)**	**Basin relief (m)**	**Relief ratio (m)**
TSB-1	663	66	597	0.09
TSB-2	863	91	772	0.11
TSB-3	435	54	381	0.06
TSB-4	444	28	416	0.05
TSB-5	741	70	671	0.10
TSB-6	315	12	303	0.03
TSB-7	658	46	612	0.09

TSB-8	501	9	492	0.06
TSB-9	535	18	517	0.06
TSB-10	568	5	563	0.07
TSB-11	607	3	604	0.05

2. **Relief Ratio (Rh):** Relief Ratio (Rh): Relief ratio is a parameter that characterizes the relationship between the total relief of a basin (elevation difference between the lowest and highest points) and the longest dimension of the basin parallel to the principal drainage line. The formula for calculating relief ratio (Rh) is not provided in the text. If you have the specific formula, please share it so that I can assist you in calculating the relief ratio for the Talpona basin.

Rh=H-h/basin length
Using formula for Relative relief,
Rh=863-3/31617.17
Rh=0.022 sq.Km
Relative relief for Talpona basin is 0.022 sq. Km.

3.The Relief Ratio (Rh) is indeed a crucial parameter in understanding the topographic characteristics of a watershed. As you mentioned, high values of Relief Ratio indicate steep slopes and high relief, while low values suggest gentle slopes and low relief. In your analysis, the highest Relief Ratio for TSB-2 suggests that this sub-watershed has steep slopes and high relief. On the other hand, the lowest Relief Ratio for TSB-11 indicates a gentle slope and low relief, as it is situated near sea level.

The insights gained from Relief Ratio, along with other morphometric parameters, contribute to the prioritization of watersheds. This prioritization can guide decisions related to soil and water conservation efforts, considering the erosive power and runoff potential of each sub-watershed.

Table 6 Prioritization Results of Morphometric Analysis

Sub-watersheds	**Rb**	**Cc**	**Dd**	**T**	**Fs**	**Rc**	**Ff**	**Re**	**Compound parameter**	**Final priority**
TSB-1	6	7	2	3	5	4	4	4	4.37	2
TSB-2	3	9	5	2	3	3	5	5	4.37	2
TSB-3	11	6	3	9	6	6	1	1	5.37	4
TSB-4	10	4	1	5	4	8	8	10	6.25	6
TSB-5	8	11	10	7	9	1	3	3	6.5	7
TSB-6	5	5	8	8	8	7	7	9	7.12	9
TSB-7	1	10	4	1	1	2	2	2	2.87	1

TSB-8	7	3	7	10	10	9	9	7	7.75	10
TSB-9	2	2	6	4	2	10	10	8	5.5	5
TSB-10	9	7	9	6	7	5	6	6	6.87	8
TSB-11	4	1	11	11	11	11	11	11	8.87	11

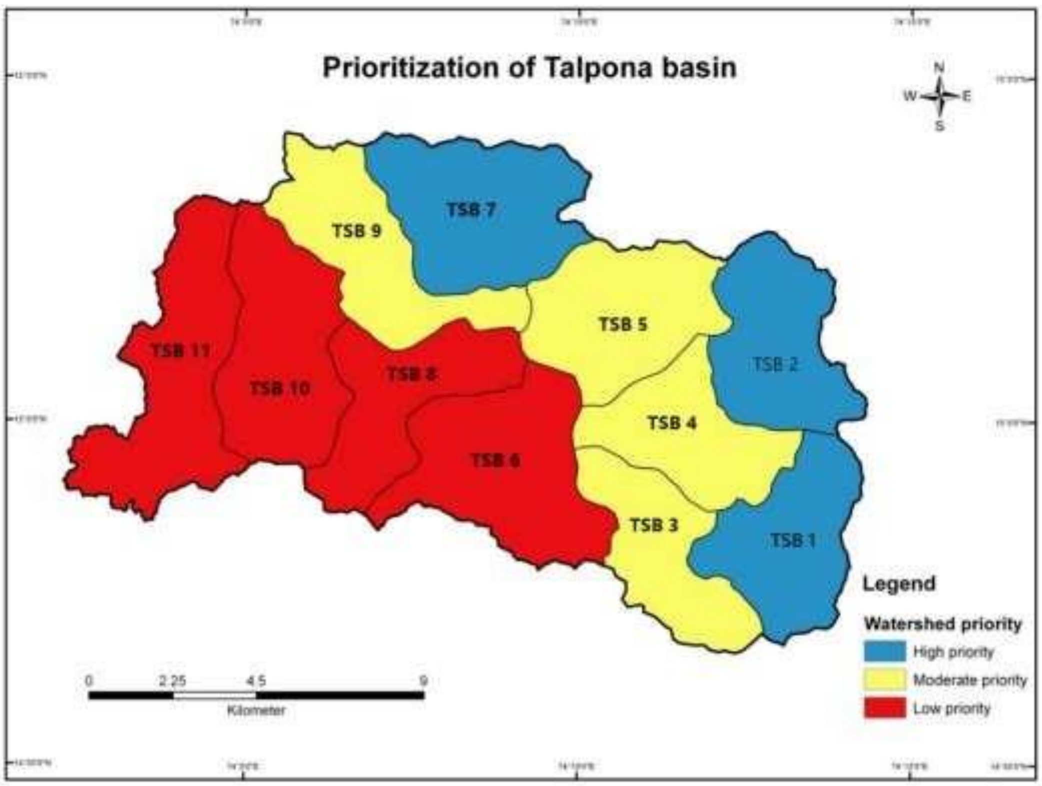

Fig.2: Sub-basin Prioritization.

The prioritization of Talpona basin into three classes (high, moderate, and low) based on the morphometric parameters provides valuable information for planning and implementing watershed management strategies. The distribution of priorities across sub-watersheds reflects the diverse topographic characteristics and erosion susceptibility within the basin. It's logical to prioritize TSB-1, TSB-2, and TSB-7 with the highest priority due to their higher elevation, steep mountain slopes, and increased susceptibility to soil erosion. These areas may require more focused soil and water conservation efforts to mitigate erosion and maintain the health of the watershed. Similarly, giving moderate priority to TSB-3, TSB-4, TSB-5, and TSB-9, which have a gentle slope and more plain topography, aligns with the understanding that such areas are less prone to erosion. The lowest priority assigned to TSB-6, TSB-8, TSB-10, and TSB-11, situated at or near sea level with almost plain topography, suggests that these areas experience minimal erosion. This prioritization helps in optimizing resource allocation for conservation measures.

Overall, this watershed prioritization can guide targeted interventions for sustainable watershed management.

Conclusion

The study's application of GIS for morphometric analysis and prioritization of sub-watersheds in Talpona watershed, Canacona, Goa, demonstrates the effectiveness of geospatial technology in understanding and managing hydrological responses. The calculated morphometric parameters provide valuable insights into the characteristics of different sub-watersheds, aiding in the prioritization process. The prioritization results align with the expected hydrologic behaviors based on elevation and slope characteristics. Sub-watersheds at higher elevations (TSB-1, TSB-2, TSB-7) are identified as having more runoff, and consequently, they receive the highest priority. This recognition is crucial for focusing conservation efforts in areas that are more susceptible to soil erosion. Similarly, sub-watersheds on gentle slopes (TSB-3, TSB-4, TSB-5, TSB-9) are given moderate priority, acknowledging their lower susceptibility to erosion. Finally, sub-watersheds near the sea (TSB-6, TSB-8, TSB-10, TSB-11) receive the lowest priority due to minimal or no erosion. The study's conclusion emphasizes the need for targeted management strategies, with a particular focus on the highly prioritized sub-basins. This approach allows for optimized resource allocation and effective watershed management practices.

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