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Using Geospatial Technology for Morphometric Analysis in the Talpona River at the Watershed level in Goa, India

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Abstract

The present study focuses on the Talpona River, which falls within south Goa, covering an area of 183.024 sq. km with a perimeter of 77 km. In the Talpona area of Canacona taluka, South Goa, it lies at 14°59'14" N latitude and 74°2'40" E longitude. The river comprises 2162 streams with a basin length of 31.67 km. The rich soil cover, thick vegetation, and adequate annual rainfall maintain the soil moisture for most of the year in the study area. Based on prioritization morphometric analysis using GIS and remote sensing techniques, the study area has been divided into 11 sub-watersheds (TSB-1 to TSB-11). The drainage density of the sub-watershed varied from 3.49 to 7.19 and the elongation ratio varied from 0.44 to 0.75, which indicates high relief and steep ground slope. These variations are due to the difference in slope, relief, and structural condition in the sub-watershed. The values of compound parameter are calculated, and the sub-watershed with low compound parameter shows the highest priority. In the present investigation, the highest priority was given to TSB-1, TSB-2, and TSB-7 because they are at a higher elevation and receive greater runoff. It will act as a good guide for efficient watershed management and conservation works in the Talpona River area.

Key word: Talpona, GIS, Remote sensing, watershed and Morphometric

Introduction

A watershed is the land area drained by a river and its tributaries, acting as a boundary for surface water drainage. The integrated use of GIS (Geographic Information System) and Remote Sensing is considered a unique, highly effective, and versatile technology for natural resource and environmental assessment, management, and monitoring. The study of the Talpona basin focuses on remote sensing and GIS techniques to augment water resource management and other activities. It thus helps improve the livelihoods of people living in the watershed area while considering ecosystem preservation. This land-use and land-cover map of the Talpona area provides a basic resource for sustainable management. Morphometric analysis of the basin allows for the study of drainage development, surface run-off, infiltration capacity, and groundwater potential. The use of GIS and remote sensing technique-based satellite imagery is helpful in executing morphometric studies of the drainage basin. The results produced regarding prioritization of the basin may provide valuable data for formulating and executing development and management programs. Similar

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research on morphometric analysis and prioritization of the Hati River watershed, Odisha, was made by Mishra Sangita S. et al. (2010) using Arc-GIS and demonstrated the utility of GIS in such studies. Pisalet al. studied morphometric analyses of the Bhogavati River Basin, Kolhapur District, Maharashtra. Present research is on morphometric analysis and prioritization of sub-watersheds in Talpona watershed, Canacona taluka of South Goa district, India. The present study will add valuable inputs for taking up effective watershed management and conservation practices in the area.

STUDY AREA

Talpona is a small fishing village situated along a coastline of the Arabian Sea in South Goa District within Canacona taluka. The Talpona River is located at 14°59'14" N latitude and 74°2'40" E longitude within Talpona area in Canacona taluka of South Goa. The study area is represented by thick soil cover, dense vegetation, annual rainfall, and almost consistent soil moisture throughout most of the year. This falls within the tropical wet, humid, and dry climatic region; hence, the mean monthly temperature has ranged between 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 area falls within the Survey of India toposheet Nos. 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 give detailed cartographic representations that help in various geographical and environmental studies in the Talpona area.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.

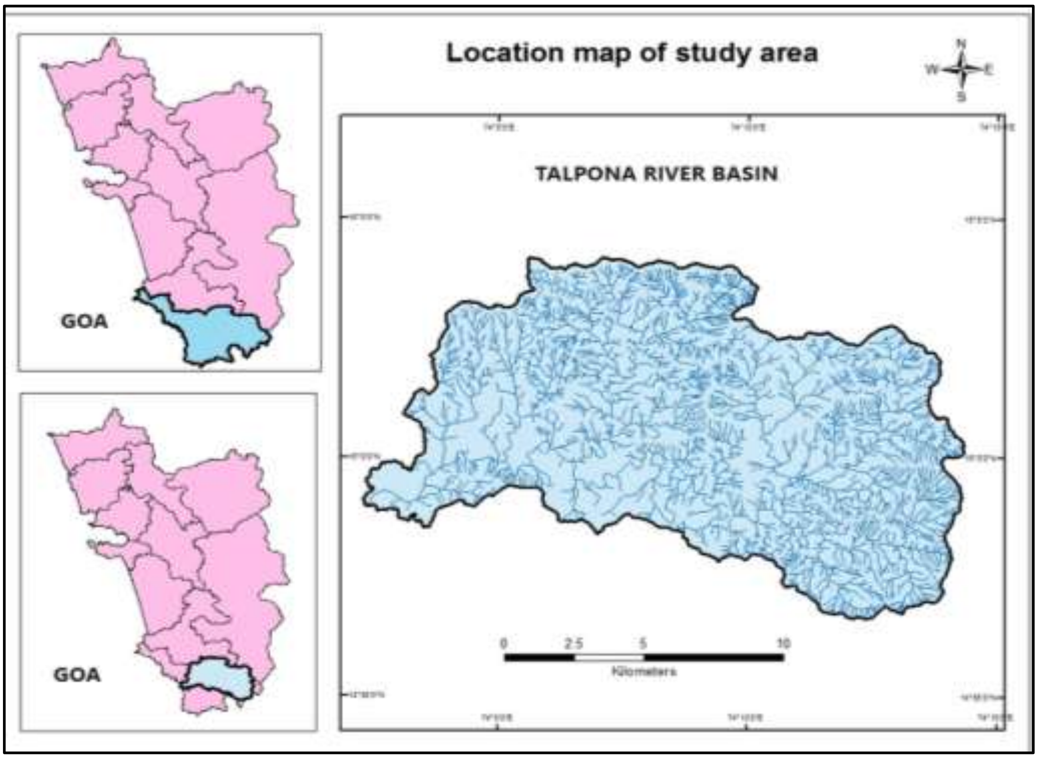

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Fig.1: Location Map of Study Area

Data and Methodology

The preponderance of this research is predicated on secondary data, chiefly obtained from ASTER, Carto DEM, and LANDSAT-8 satellite imagery, as well as from 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 underwent a scanning process, after which both the toposheets and satellite imagery were subjected to mosaicing techniques. Thereafter, the mosaiced images were georeferenced utilizing geographical coordinates, with projections designated as WGS 1984 datum within the 43 North zone. The process of digitization was executed employing ArcGIS software, which involved the formulation of a geodatabase file encompassing a feature dataset and feature class. Manual digitization was conducted for delineating the basin boundary, streams, and other features. The determination of stream ordering was executed in accordance with Strahler's methodology (Strahler, 1964), while topology was constructed to amend any digitization inaccuracies. The basin was delineated manually utilizing the ridge line. Hydrological tools available in ArcGIS were applied to the satellite data, commencing with the fill tool to rectify voids in the imagery, subsequently followed by the flow direction tool to ascertain the flow dynamics within the basin. The flow accumulation tool was then utilized to evaluate water accumulation within the basin, which facilitated the automatic delineation of the basin. Stream ordering was again performed utilizing Strahler's methodology. The morphometric analysis, influenced by the research of Mishra Sangita S. et al. (2010), employed formulas from Horton (1945), Strahler (1964), Schumm (1956), Nookaratnam et al. (2005), and Miller (1953) for the computation of morphometric parameters. Furthermore, Manjare et al. (2014) and Narendra Kumar (2013) have executed morphometric analyses across various river basins, demonstrating the efficacy of Geographic Information Systems (GIS) and remote sensing technologies. In the current investigation, morphometric analysis and prioritization ratings for all eleven sub-watersheds within the Talpona watershed were established through the computation of compound parameter values. The sub-watershed exhibiting the lowest compound parameter value was accorded the highest priority within the prioritization framework.

Result and Discussion

The Talpona watershed is systematically partitioned into eleven distinct sub-watersheds, designated by the codes TSB-1 through TSB 11.

Linear aspect:

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1. Stream Order (U): The Talpona River encompasses seven distinct stream orders, characterized by an intricate network of 2162 stream segments that collectively cover an expanse of 183.024 square kilometers.

2. Stream Number (Nu): The stream number (Nu) is quantitatively defined as the aggregate tally of stream segments categorized within each order. The Talpona River basin has been methodologically classified into seven stream orders. The stream numbers for the entire basin, as well as its discrete sub-watersheds, have been systematically presented 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 is noted for a basin length measuring 31.67 km. The sub-watersheds within the Talpona River basin exhibit variability in basin lengths; TSB-11 is recorded as having the most extensive length at 11.34 km, succeeded by TSB-6 at 9.99 km. In contrast, TSB-1 is identified as having the shortest basin length at 6.04 km (refer to Table 1).

4. Stream Frequency (Fs): Stream frequency, as articulated by Horton (1945), is defined as the count of stream segments per unit area, serving as a critical parameter in hydrological studies. The stream frequencies for all sub-watersheds are elaborated upon in Table 1. The findings of the study indicate that sub-watersheds characterized by substantial forest cover demonstrate diminished drainage frequency, whereas those with increased agricultural land

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exhibit heightened drainage frequency. Notably, TSB-7 (17.46) and TSB-9 (15.92) manifest elevated drainage frequencies, implying augmented runoff relative to other sub-watersheds. Conversely, TSB-11 is observed to have a reduced drainage frequency of 7.07.

5. Stream Length (Lu): Stream length, as defined by Horton (1945), denotes the cumulative length of individual stream segments corresponding to each order. The stream lengths have been computed for the entire basin as well as its eleven sub-watersheds (see Table 2). The analyses reveal a trend of decreasing total lengths of stream segments as the stream order escalates. Table 2 delineates the ratios of stream lengths across the sub-watersheds.

Table 2 Order wise stream length of sub-watersheds

Sub-watershed	Order wise stream length (Lu) meters								Stream leng		
	1	2	3	4	5	6	7	Total	2/1	3/2	4/3
TSB-1	54415.19	17943.84	11361.82	2203.78	8607.59	-	-	94533.04	0.32	0.63	0.19
TSB-2	54515.81	15566.33	8201.16	6182.06	5093.70	-	-	89559.09	0.28	0.52	0.75
TSB-3	32088.47	14458.42	7426.60	5051.57	8617.16	17293	-	84935.26	0.45	0.51	0.68
TSB-4	40919.83	13157.50	9473.06	3020	8607.59	17293	-	94271.01	0.32	0.71	0.31
TSB-5	35914.38	14196.30	6883.67	6994.29	3523.45	-	-	67512.11	0.39	0.48	1.01
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
TSB-8	29.757.05	9417.53	3867.94	1847.77	-	24839.16	11086.20	80815.67	0.31	0.41	0.47
TSB-9	49199.73	16456.14	11371.89	2226.65	6157.29	7546.16	-	92957.88	0.33	0.69	0.19
TSB-10	40982.09	15630.08	5690.61	4128.60	2323.27	-	11086.20	79840.86	0.38	0.36	0.26
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 quantitatively defined as the ratio of the number of stream segments within a specific order to the number of segments within the subsequent higher order (Schumm S. A., 1956). Generally, higher elevations are associated with elevated bifurcation ratios, and vice versa. This phenomenon can be attributed to the prevalence of first-order streams in higher elevations, which subsequently converge to form

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streams of the next higher order. The bifurcation ratios for the sub-watersheds of Talpona are enumerated in Table 3. Notably, TSB-7 is distinguished by the highest bifurcation ratio of 3.56, attributed to its elevated topography, which facilitates the formation of a greater number of first-order streams that converge to create second-order streams and beyond. In contrast, TSB-3 exhibits the lowest bifurcation ratio at 2.56, a consequence of its positioning on a gentle slope, leading to a reduced number of first-order streams and, correspondingly, a diminished bifurcation ratio. Elevated bifurcation ratios are typically indicative of enhanced 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): The Talpona River encompasses a basin area measuring 183.024 square kilometers. The delineated areas pertinent to the sub-watersheds are comprehensively presented in Table 4.

2. Basin Perimeter (P): The term basin perimeter refers to the outer boundary that encompasses the watershed's area. The Talpona River exhibits a perimeter of 77 kilometers, with the specific measurements of the perimeters for each sub-watershed delineated in Table 4.

3. Form Factor (Ff): The form factor, defined as the ratio of the basin area to the square of the basin length, has been computed for all sub-watersheds, yielding values ranging from 0.15 to

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0.45 (as detailed in Table 4). The recorded values imply that the sub-watersheds exhibit an elongated morphology, with elevated Ff values indicative of greater elongation. An increased Ff denotes basins characterized by prominent peaks and shorter flood durations, thereby facilitating more manageable flood flows.

4. Elongation Ratio (Re): The elongation ratio is quantitatively expressed as the ratio of the diameter of a circle possessing an equivalent area to that of the basin, compared to the maximum length of the basin. The elongation ratio values for the sub-watersheds range from 0.44 to 0.75 (refer to Table 4). Notably, TSB-11 is identified as exhibiting greater elongation, whereas TSB-1, TSB-2, TSB-4, TSB-6, TSB-8, TSB-9, and TSB-10 are classified as elongated. Conversely, TSB-3, TSB-5, and TSB-7 are categorized as less elongated.

5. Circularity Ratio (Rc): The circularity ratio, which represents the relationship between the watershed area and the area of a circle with an equivalent perimeter, displays variability from 0.30 to 0.66 across the sub-watersheds (as indicated in Table 4). The distinctive circularity ratio observed for TSB-5 is attributable to steep slopes, significant relief, and specific structural characteristics.

6. Compactness Coefficient (Cc): The compactness coefficients are delineated in Table 4, exhibiting a range from 1.20 to 1.82 across the sub-watersheds. TSB-5 is characterized by the lowest compactness coefficient of 1.20, while TSB-11 demonstrates the highest value of 1.82. The calculated compactness percentage for each sub-watershed indicates that TSB-11 is relatively more compact, representing a compactness of 11.57%.

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

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7. Drainage Density (Dd): Drainage density, defined as the length of streams per unit area within the watershed (Horton, 1945), exhibits variability across the sub-watersheds, ranging from 3.49 to 7.19 (refer to Table 4). TSB-11 presents the lowest drainage density of 3.49, which suggests the presence of highly resistant, impermeable subsoil materials coupled with dense vegetation and low relief. In contrast, TSB-4 reveals the highest drainage density of 7.19, indicating weak or impermeable surface materials along with reduced vegetation and elevated relief.

8. Drainage Texture (Dt): Drainage texture, which quantifies the total number of stream segments of all orders per unit perimeter of the area (Horton, 1945), is categorized into five classifications: very coarse (<2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8), and very fine (>8). The drainage texture of the Talpona River basin varies from 4.95 to 16.82 (as illustrated in Table 4). TSB-2 and TSB-7, identified as highly elevated regions exhibiting steep slopes and very high drainage densities (13.14 and 16.82, respectively), suggest enhanced surface runoff. Conversely, TSB-11, with the lowest drainage texture recorded at 4.95, implies a greater capacity for infiltration and a more gradual slope.

- **Relief Aspect**

1. Basin Relief (H): Basin Relief: Basin relief refers to the difference in elevation between the highest and lowest points of the valley floor. In Talpona basin, the maximum relief is 863 while the minimum value of relief is 3, hence the total relief is 860. Specific values for each sub-watershed are given in the table below.

Table 6 Relief ratio of sub-watersheds

Sub- watersheds	Highest relief (m)	Lowest relief (m)	Basin relief (m)	Relief ratio (m)

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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

1. Relief Ratio (Rh): Relief Ratio (Rh): It is the relief ratio, which describes the relationship between the total relief of the basin, considering the elevation difference between the lowest and highest points, and the longest dimension of the basin parallel to the principal drainage line. The formula for the calculation of relief ratio (Rh) is not presented here; kindly provide the specific formula so that I can help you calculate the relief ratio for the Talpona basin.

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

The relative relief for Talpona basin is 0.022 sq. Km.

3. The Relief Ratio (Rh) is indeed an important parameter that explains the topographic characteristics of a watershed. As stated, high relief ratios are indicative of steep slopes and high relief, while low values are indicative of gentle slopes with low relief. According to your calculations, the highest Relief Ratio for TSB-2 indicates steep slopes and high relief in this sub-watershed. On the other hand, the lowest Relief Ratio for TSB-11 indicates a gentle slope and low relief since it is near sea level. The insights developed on the Relief Ratio along with other morphometric parameters will provide useful data in prioritizing the watersheds. This could help in decision-making on soil and water conservation methods to be implemented, based on the erosion potential and runoff of each sub-watershed.

Conclusion

The study's application of GIS for morphometric analysis and prioritization in sub-watersheds in the Talpona watershed, Canacona, Goa, shows how geospatial technology could be put to effective use to understand and manage hydrological responses. The calculated morphometric parameters provide valuable insight into the characteristics of different sub-watersheds,

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which have helped in prioritizing them. Prioritization based on the analysis gives a very logical output in tune with the expected hydrologic behaviors of catchments based on characteristics such as elevation and slope. Sub-watersheds lying at higher elevations (TSB-1, TSB-2, TSB-7) are identified as having more runoff; thus, they have been given the highest priority. These need special focus for conservation efforts because these catchments are more susceptible to soil erosion. Similarly, sub-watersheds on gentler slopes (TSB-3, TSB-4, TSB-5, TSB-9) get a medium priority since these have lower susceptibility to erosion. Finally, sub-watersheds near the sea (TSB-6, TSB-8, TSB-10, TSB-11) have the lowest priority because they have minimum or no erosion. In the conclusion, the study suggests targeted management strategies, especially for highly prioritized sub-basins, which would result in optimized resource allocation and thereby ensure effective watershed management practices.

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