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GEOINFORMATICS-BASED MORPHOMETRIC CHARACTERIZATION AND SUB-WATERSHED RANKING IN THE KRISHNAI RIVER BASIN

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Abstract- The primary aim of this study is to conduct a comprehensive morphometric characterization of the Krishnai River Basin and to rank its sub-watersheds based on their susceptibility to soil erosion. By leveraging geoinformatics techniques, namely Geographic Information System (GIS) and Remote Sensing (RS), this research seeks to provide a detailed understanding of the basin's morphometric parameters and their implications for watershed management. The study aims to identify priority areas for intervention and develop strategies for sustainable water resource management and soil conservation. The basin was divided into five sub-watersheds (SW1 – SW5) for the purpose of detailed characterization. The basin covers an area of 932.03 km² with a perimeter of 245.70 km and an elevation range from 0 m to 894 m. The slope within the watershed varies from 0º - 46.95º, indicating a range from nearly level surfaces to very steep slopes. The basin features a 6th order dendritic drainage pattern, consisting of a total of 763 streams with a combined stream length of 1046.63 km.

Keywords: **Morphometric analysis, prioritization, GIS, Remote Sensing, River Basin.**

1. INTRODUCTION

Watershed management has become increasingly important due to growing environmental challenges like soil erosion, sedimentation, and water scarcity. To tackle these issues effectively, it is essential to understand the geomorphological characteristics of a watershed. Morphometric analysis, which involves the quantitative assessment of the earth's surface and the shape and dimensions of its landforms, is crucial in this regard.

The integration of geoinformatics, particularly Remote Sensing (RS) and Geographic Information System (GIS) technologies, has greatly enhanced the precision and efficiency of morphometric analysis. The Krishnai River, a tributary of the Brahmaputra River is frequently prone to flooding. The study focuses on the entire Krishnai River Basin (Fig-1) up to the confluence of the Krishnai and Dudhnai rivers before it joins the Brahmaputra River. The Krishnai River Basin, which has an area of 932.03 km^2, is located between 26°4' N & 25°34' N and 90°20' E & 90°45' E, spanning four Indian districts: Goalpara (6.33%) in Assam and East (45.05%), West (7.61%), and North Garo Hills (40.99%) in Meghalaya. By conducting a thorough morphometric analysis of the Krishnai River Basin, it is possible to identify areas that are particularly vulnerable to erosion. This information can be used to implement targeted soil and water conservation measures, such as reforestation, construction of check dams, and creation of buffer zones.

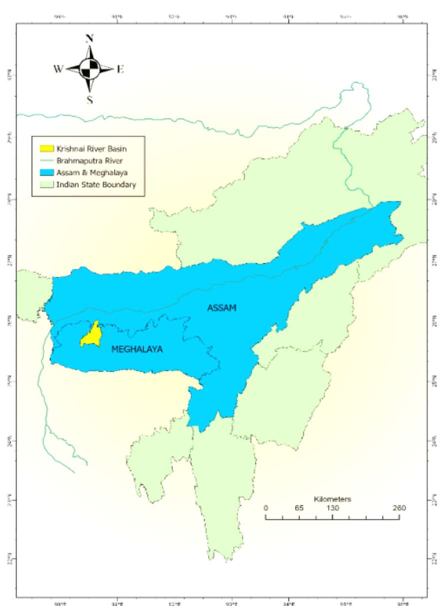

Fig- 1: Geographic Location of Krishnai River Basin

2. LITERATURE REVIEW

The field of morphometric analysis has significantly evolved with the integration of Remote Sensing (RS) and Geographic Information System (GIS) technologies, facilitating more precise and efficient watershed management. Foundational works by (Horton, 1945; Strahler, 1964) established essential quantitative methodologies and concepts such as stream ordering, bifurcation ratios, drainage density, and stream frequency, which are critical for analyzing watershed characteristics and hydrological behavior. (Clarke, 1966) further expanded on these principles by emphasizing the importance of relief aspects in geomorphological studies. (Sreedevi et al., 2009) studied the Wailapalli watershed's drainage morphometry using SRTM data and GIS which revealed an elongated basin shape due to thrusting and faulting, dominance of lower order streams, high discharge capability, and low groundwater potential, aiding in rainwater harvesting and watershed management.Similarly, (Pankaj & Kumar, 2009) provided insights into soil erosion and sediment yield in the Song Basin through detailed sub-watershed analysis using GIS. (Javed et al., 2009) applied RS and GIS to the Kanera Watershed, Guna, Madhya Pradesh demonstrating the effectiveness of these technologies in identifying critical intervention areas and developing targeted watershed management strategies. (Bhatt & Ahmed, 2014) showcased the potential of geoinformatics in prioritizing sub-watersheds for soil conservation in the Upper Krishna Basin. (Reddy et al., 2004)highlighted the application of GIS in analyzing drainage patterns and basin geometry in the Vena River Basins, respectively. (Singh et al., 2013) employed RS and GIS to study the Morar River Basin, emphasizing the importance of these technologies in large-scale watershed management. Morphometric analysis of the Kulsi River Basin using remote sensing and GIS was conducted by (Das & Sarma, 2023) to understand drainage characteristics and sediment contribution, crucial for extending reservoir lifespan. The study focused on the watershed up to the dam site proposed by the Brahmaputra Board, Central Water Commission and Government of Assam, identifying key sediment-contributing regions. (Thakuriah & Saikia, 2018) emphasized the need for flood hazard mapping in the Krishnai river basin, Assam. They created a hazard index using variables such as flood frequency, drainage density, slope, and population density, aiming to produce a flood hazard map for better flood preparedness and emergency response. Geographic Information System (GIS) was used to visualize high-risk areas and support development planning. (Ali & Kashyap, 2018)analysed 46 years of annual peak flood discharge data for the Krishnai River at Velterghat station (1972-2018) using the Log Pearson Type III distribution model. The analysis helps estimate future flood events and can inform flood infrastructure design decisions for policymakers. Collectively, these studies underscore the transformative impact of RS and GIS technologies on morphometric analysis. They demonstrate how integrating spatial data and advanced analytical tools can enhance the understanding of watershed characteristics, facilitate the identification of vulnerable areas, and inform effective management and conservation strategies. This extensive body of literature provides a robust foundation for the present study on the Krishnai River Basin, highlighting the need for a comprehensive morphometric analysis and sub-watershed ranking to address the basin's unique environmental challenges.

3. METHODOLOGY

The methodology for this study involves the use of geoinformatics tools, specifically Geographic Information Systems (GIS) and Remote Sensing (RS) data, to perform a comprehensive morphometric characterization and ranking of sub-watersheds in the Krishnai River Basin. This approach integrates various datasets and analytical techniques to ensure accurate and meaningful results. The methodology is divided into four main phases: Data Acquisition, Data Processing, Morphometric Characterization, and Ranking of Sub-watersheds on the basis on erosion susceptibility. **The Methodology Flowchart is presented in fig-2.**

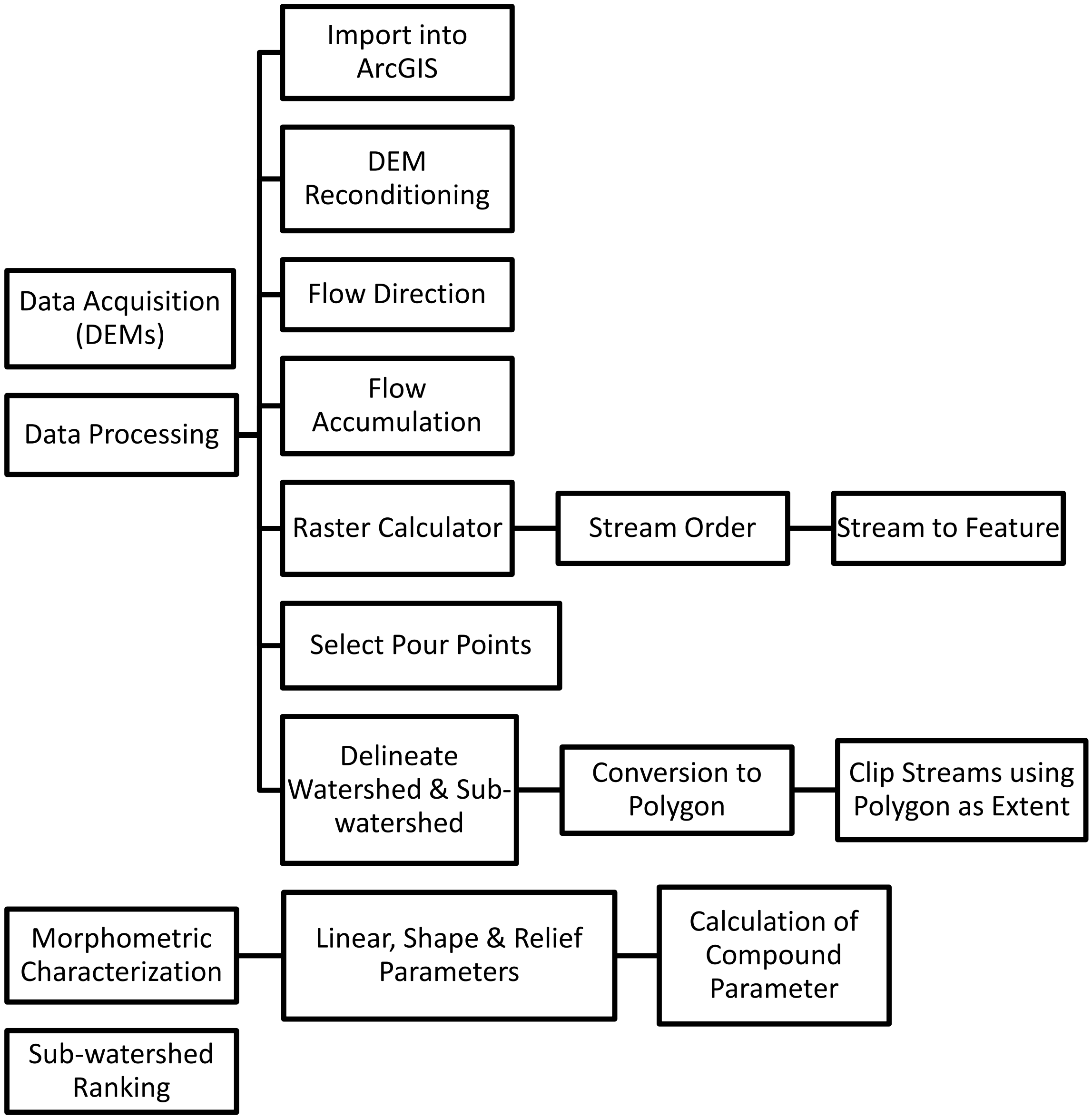

Fig-2: Methodology Flowchart

Digital Elevation Model (DEM) raster, from Bhuvan Portal of spatial resolution of 1 arc-sec (~32 m).DEMs are used to provide detailed and accurate elevation data for terrain analysis, enabling the delineation of watersheds, calculation of terrain attributes, and morphometric characterization. Topographical Sheets of scale 1:50000 pertaining to the Goalpara, North Garo Hills, East Garo Hills, and West Garo Hills are also acquired from the Survey of India Portal. Topo sheets are used alongside DEMs to validate accuracy, provide additional details, enhance feature extraction, fill data gaps, and offer historical context for comprehensive morphometric analysis.

The acquired data is imported into ArcGIS software of version 3.3.0. Various DEM reconditioning procedures are done using built-in function of ArcGIS, like mosaicking, projecting and filling. Flow direction raster is generated from its down slope neighbor, or neighbors, using the D8 method. The D8 flow method determines the direction of water flow from each cell in a raster grid to one of its eight neighboring cells (1, 2, 4, 8, 16, 32, 64, 128 based on the steepest descent. Flow Accumulation Tool is used to generate

Flow Accumulation Raster. Each cell of the raster indicates its accumulated flow, calculated by summing the number of upstream cells that drain into it. The Raster Calculator is used for generating stream raster by trial-and-error method. It facilitates the manipulation of DEM and flow accumulation data to derive specific hydrological characteristics.Using the stream network derived from flow accumulation, the Stream Order tool is used. Strahler's method is used for stream ordering. Strahler's stream ordering method assigns a numerical order to streams in a drainage basin based on their hierarchy. The smallest tributaries with no branches are designated as first-order streams. When two streams of the same order join, the resulting stream is assigned the next higher order, ensuring a structured and hierarchical classification of the river network. The Stream to Feature tool is used to convert the raster stream network into vector format, making it easier to analyze and visualize the stream data. Pour points are selected at the outlet of the overall watershed as well as at the outlets of the sub-watersheds. The Watershed tool in ArcGIS was used to delineate the Krishnai River Basin, which was further divided into five sub-watersheds, into a raster file. Streams and watershed boundaries are converted into polygon and the streams are clipped to the extent of the watershed polygon.

Morphometric characterization is the quantitative analysis of the shape, dimensions, and geometrical properties of a drainage basin or watershed. Linear parameters (drainage density, drainage frequency, bifurcation ratio, drainage texture and length of overland flow), shape parameters (form factor, shape factor, compactness coefficient, elongation ratio, and circularity ratio) and relief parameters (ruggedness number and relief ratio) are thereby analyzed and calculated from the processed data and weights are assigned to each sub- watershed against each of the morphometric parameter based on their relative susceptibility to soil erosion.

Ranking of sub-watersheds is done to prioritize areas for conservation, management, and further study based on their morphometric characteristics. The sub-watershed corresponding to the highest value of compound parameter requires the most attention due to its high susceptibility to soil erosion and flooding.

4. RESULTS AND DISCUSSIONS

Morphometric characterization refers to the quantitative analysis of the shape, dimensions, and various geometric properties of landforms and drainage basins. This analysis involves measuring and evaluating different parameters to understand the physical structure and hydrological behavior of a watershed. Linear parameters are quantitative measures used to describe the physical dimensions and characteristics of drainage basins and their stream networks. Essentially, they are the one-dimensional morphometric properties pertaining to drainage basins. The drainage perimeter, also known as the basin perimeter or watershed boundary, is the outer boundary of a drainage basin that defines the area of land where precipitation collects and drains off into a common outlet, such as a river, bay, or other body of water. The drainage perimeter is crucial for understanding hydrological processes, water flow patterns, and watershed management. The drainage perimeter is calculated using ArcGIS Pro 3.3.0. The drainage perimeter of the Krishnai River Basin is 245.70 km.

Stream order is a method of classifying the hierarchy of natural channels within a watershed based on their relative size and position in the stream network. Strahler order method for classifying streams is adopted in which first-order streams are the smallest, with no tributaries; when two streams of the same order merge, they form a stream of the next higher order. This system helps in understanding the structure and complexity of drainage networks. According to this classification, the Krishnai River is a 6^{th} order stream. Since, lower order streams are typically smaller and flow at steeper gradients; they create greater velocity in the water, which exerts more force on the soil particles, making them more susceptible to soil erosion.

Stream number, often referred to as stream frequency, is the count of stream segments of a particular order within a drainage basin. It provides insight into the drainage density and the branching pattern of a river network. The stream number decreases as the stream order increases, reflecting fewer, larger streams as you move downstream in the hierarchy. The stream number in the Krishnai River Basin is 763. Stream length refers to the total distance along the course of a stream or river from its source to its mouth. For sub-watershed wise ranking of the sub-watersheds, the stream length is calculated by summing the total length of streams of each of the orders. Longer streams have higher erosion potential and sediment transport capacity due to increased flow distance and energy. The stream length of the entire basin is 1046.63 km.

Drainage density describes the spatial distribution of a drainage network within a watershed. High drainage density indicates a well-developed drainage network, which can lead to quick runoff and less infiltration. On the contrary, low drainage density suggests a less developed network with more infiltration and slower runoff. The drainage density of Krishnai River Basin is 1.186 km/km^2 ranging from 1.205 km/km^2 for SW2 and 1.076 km/km^2 for SW4. Low drainage density (≤ 1.00 km/km^2) indicates fewer stream channels, leading to less runoff and reduced erosion potential. Moderate drainage density (1.01 to 2.00 km/km^2) shows a balanced stream network, with moderate runoff and erosion. High drainage density (around 3.00 km/km^2) suggests an extensive stream system, increasing runoff and erosion risks. Very high drainage density (>3.00 km/km^2) reflects a dense stream network, resulting in substantial runoff, minimal infiltration, and heightened soil erosion susceptibility. The increased erosive force of surface water in areas with high drainage density makes them more prone to soil degradation. Table-2 shows the Morphometric Parameters of Krishnai River Basin.

Table-1: Morphometric Parameters

	Morphometric Parameters	**SW1**	**SW2**	**SW3**	**SW4**	**SW5**
Linear Parameters	Drainage Perimeter (P), km	52.9	61.8	100.53	125.38	130.35
	Streams No. (N_u)	75	97	126	270	195
	Stream Length (L_u), km	102.33	128.62	179.82	372.41	263.45
	Stream Length Ratio (R)	0.44	0.45	0.69	0.55	0.58
	Basin Length (L_b), km	16.75	18.62	23.29	36.32	28.95
	Bifurcation Ratio (R_b)	4.37	7.14	4.67	4.01	3.71
	Length of Overland Flow (L_o), km	0.433	0.415	0.44	0.465	0.441
	Drainage Density (D_d), km/km^2	1.155	1.205	1.136	1.076	1.135
	Drainage/Stream Frequency (D_f), Streams/km^2	0.846	0.909	0.796	0.780	0.840
	Drainage Texture (T), km^{-1}	1.437	1.602	1.253	2.153	1.496
Areal Parameters	Drainage Area (A), km^2	88.62	106.75	158.35	346.16	232.12
	Form Factor (R_f)	0.316	0.308	0.292	0.262	0.277
	Shape Factor (B_s)	3.168	3.249	3.428	3.812	3.611
	Circularity Ratio (R_c)	0.398	0.351	0.197	0.277	0.172
	Elongation Ratio (R_e)	0.634	0.626	0.609	0.578	0.594
	Compactness Coefficient (C_c)	0.084	0.082	0.09	0.051	0.079
	Constant of Channel Maintenance (C_m), km^2/km	0.866	0.83	0.881	0.93	0.881
Relief Aspects	Relief (H), km	0.354	0.359	0.492	0.879	0.626
	Relief Ratio (R_h)	0.0211	0.0058	0.0049	0.007	0.0048
	Relative Relief Ratio (R_r)	0.00669	0.0058	0.00489	0.00701	0.0048
	Ruggedness Number (R_n)	0.409	0.433	0.559	0.946	0.710

Bifurcation ratio is used to quantify the branching pattern and complexity of a river network within a drainage basin. The bifurcation ratio of the entire catchment is 4.78, with values ranging from 7.14 for SW2 and 3.71 for SW5. High bifurcation ratio (R_b> 5) is typically associated with higher runoff and greater susceptibility to soil erosion because the water is more concentrated and flow faster, causing more erosion.

Drainage area refers to the total surface area from which runoff is collected and drained through a common outlet, such as a river, stream, or other water bodies. The total catchment area of the Krishnai River Basin is 932.03 km^2.

Ranking of sub-watersheds refers to the process of evaluating and ordering sub-watersheds within a larger watershed based on specific criteria, such as susceptibility to soil erosion, hydrological response, or other environmental factors. The goal is to identify which sub-watersheds are most at risk or have the highest priority for conservation and management efforts. The present study emphasizes on the criteria of susceptibility to soil erosion.

Integral weights, ranging from 1 to 5, are assigned to the sub-watersheds against each of the morphometric parameters with 1 indicating the most susceptible to soil erosion and 5 indicating the least susceptible. A compound parameter (C_p) is calculated by averaging the integral weights against each of the sub-watersheds. The sub-watersheds are then ranked based on their compound parameter, indicating their susceptibility to soil erosion. The lowest value of C_p will indicate a sub-watershed with the highest susceptibility to soil erosion, and vice versa.

Table-2: Compound Parameter for Sub-watersheds of Krishnai River Basin

	Morphometric Parameters	SW1	SW2	SW3	SW4	SW5
Linear Parameters	Bifurcation Ratio (R_b)	3	1	2	4	5
	Length of Overland Flow (L_o)	4	5	3	1	2
	Drainage Density (D_d)	2	1	3	5	4
	Drainage/Stream Frequency (D_f)	2	1	4	5	3
	Drainage Texture (T)	4	2	5	1	3
Areal Parameters	Form Factor (R_f)	5	4	3	1	2
	Shape Factor (B_s)	1	2	3	5	4
	Circularity Ratio (R_c)	5	4	2	3	1
	Elongation Ratio (R_e)	5	4	3	1	2
	Compactness Coefficient (C_c)	4	3	5	1	2
Relief Parameters	Relief Ratio (R_h)	1	3	4	2	5
	Ruggedness Number (R_n)	5	4	3	1	2
Compound Parameter (C_p)		3.4	2.8	3.3	2.5	2.9

Linear and relief morphometric parameters share a direct relationship with erosion susceptibility, meaning they increase and decrease in concert. The areal morphometric parameters share an inverse relationship with erosion susceptibility. Thus, the highest value of linear and relief parameters against a sub-watershed is ranked 1 (most erosion susceptible). But the highest value of areal parameter against a sub-watershed is ranked 5 (least erosion susceptible). Table-2 shows the ranking of the five sub-watersheds on against the morphometric parameters. The compound parameter is classified into three categories; ≤ 2.5 (high erosion susceptibility), between 2.5 - 3.0 (medium erosion susceptibility) and ≥ 3 (low erosion susceptibility). Table-3 shows the final ranking of the sub-watersheds of Krishnai River Basin.

Table-3: Final Ranking of the Sub-watersheds of Krishnai River Basin

Sl.No.	Sub-watershed	C_p	Final Rank	Erosion Susceptibility
1	SW1	3.4	V	Low
2	SW2	2.8	III	Medium
3	SW3	3.3	IV	Low
4	SW4	2.5	I	High
5	SW5	2.9	II	Medium

Final ranking of the sub-watersheds of the Krishnai River Basin on its susceptibility to soil erosion is shown in Table 4.22. SW4 has the least value of C_p, indicating its 'high' erosion susceptibility, followed by SW5 and SW2, which falls under 'medium' erosion susceptibility, and the remaining two sub-watersheds, SW3 and SW1 falls under 'low' erosion susceptibility. Fig. 4.3 shows the visual representation of the ranking of the sub-watersheds based on the compound parameter.

The highest priority suggests its significant degree of soil erosion, making it essential to implement soil conservation measures. In the Krishnai River Basin, SW4 is identified as the most erosion-susceptible area, and thus, any soil conservation measures should commence from it. Subsequent measures should follow in other sub-watersheds based on their susceptibility

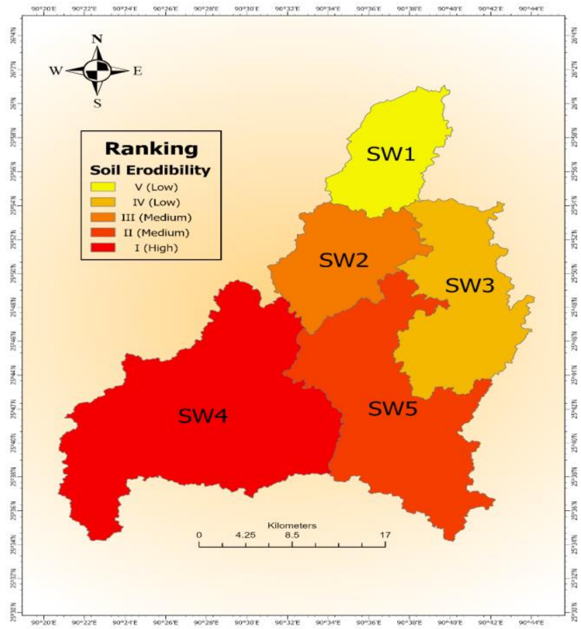

Fig-3: Ranking of Sub-watershed Based on Susceptibility to Soil Erosion

5. CONCLUSION

The study focused on the morphometric characterization and prioritization of sub-watersheds in the Krishnai River Basin using Cartosat-1 DEM data of 1 arc-sec spatial resolution. The basin was divided into five sub-watersheds (SW1 – SW5) for the purpose of detailed characterization. The basin covers an area of 932.03 km² with a perimeter of 245.70 km and an elevation range from 0 m to 894 m. The slope within the watershed varies from 0º - 46.95º, indicating a range from nearly level surfaces to very steep slopes. The basin features a 6th order dendritic drainage pattern, consisting of a total of 763 streams with a combined stream length of 1046.63 km. In the Krishnai River Basin, SW4 is identified as the most erosion-susceptible area, and thus, any soil conservation measures should commence from it. Subsequent measures should follow in other sub-watersheds based on their susceptibility.

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