

# Prioritization of sub-watershed through morphometric analysis, Principal Component, and Land Use/Cover: A Case study of Cachar District, India

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**Abstract:** Soil and watershed management relies heavily on watershed prioritization. Examining flood risk assessment using morphometric parameters and land use/land cover (LULC) datasets analyzed using GIS, this study focuses on watershed prioritization in the Cachar district. To calculate linear, areal, and relief morphometric parameters and to demarcate sub-watersheds, a 30 m resolution ALOS DEM was used. To evaluate LULC parameters, we also used Esri LULC 2023, which is based on Sentinel-2 imagery with a resolution of 10 meters. To establish priorities, an integrated method based on Principal Component Analysis (PCA) was used. When it comes to watershed prioritization, principal component analysis (PCA) is well-known for its adaptability and efficiency in choosing important correlated parameters. Priority was given to the sub-watershed that had the lowest compound value. Stream orders varied from 2 to 4, and the district was subdivided into 6 sub-watersheds. With a stream order of 4, sub-watershed 5 (SW\_5) had the highest order, and sub-watershed 4 (SW\_4) had the lowest.

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## 1 Introduction

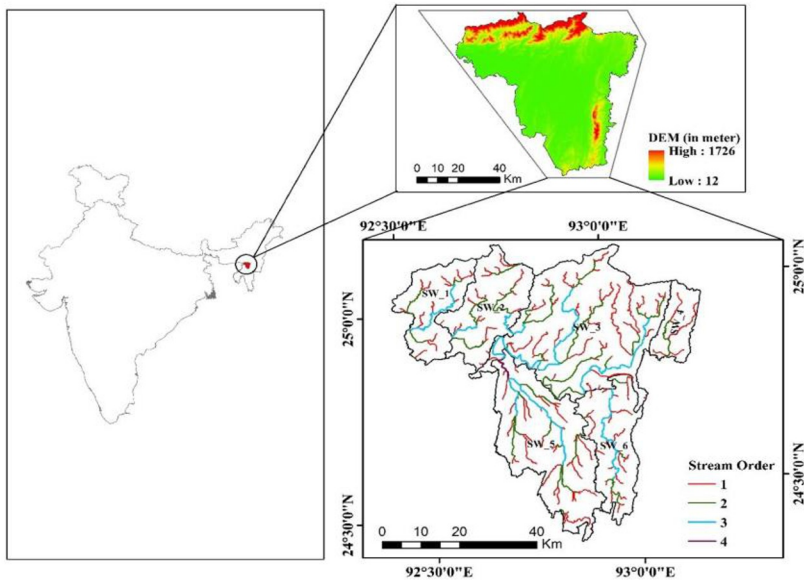
The field of geomorphometry is concerned with the quantitative study of landforms through the application of mathematical, statistical, and image analysis techniques. Its purpose is to assess a region's environment, hydrology, morphology, and other features [1]. A watershed refers to the region where rainfall runoff converges and flows through a singular point into larger bodies of water such as streams, lakes, rivers, and oceans. A watershed is a hydrologic unit that occurs naturally and is characterized by shared climatic, topographic, and other physical conditions in its surroundings. Various terms have been employed to establish the hierarchy of watersheds, such as sub-watershed, basin, and sub-basin [2]. To prioritize sub-watersheds, GIS and remote sensing analyses of morphometric parameters are indispensable[3]. Hydrological studies and drainage basin management both rely heavily on morphometric analysis. Preserving both surface and subsurface water resources is an important part of watershed management. When creating a plan for watershed management, many considerations must be made, including the area's topography, lithology, erosional condition, and drainage pattern[4]. Morphometric parameters provide additional information about the physical characteristics of a catchment area and their relationship to floods[5]. In addition to reducing the negative impacts of surface runoff and floods, watershed management seeks to maximize the use of surplus water for useful purposes such as irrigation, recharging groundwater supplies, and preventing erosion[6]. Natural disasters like floods happen in almost every country on Earth. They affect people in many different ways, both economically and socially, and sometimes even kill them[7]. Eighty-two % of the world's population lives in areas that substantially overlap with regions where flood events occur more frequently than 30% of the time. River basins, coastal zones, floodplains, and the areas around them are home to about 2 billion people, making flood hazards and related risks a global concern in these areas. It has multiple abrupt and detrimental effects on people's lives and livelihoods, particularly in the agricultural sector[8,9]. Rainfall patterns, drainage systems, infiltration rates, environmental conditions, evapotranspiration processes, and human activities affect flood susceptibility[10]. On a national or regional level, there is a notable dearth of such research. As a result, this study uses geospatial methods for morphometric analysis to rank sub-watersheds related to flooding or flash floods. The study's conclusions will help decision-makers in flood-prone areas that have a lot of potential for runoff harvesting put in place the right policies.

## 2 Materials and Methodology

### 2.1 Study Area

The Cachar district is situated in the central part of Assam's Barak Valley, covering the geographical coordinates of North Latitudes 24°8' to 25°8' and East Longitudes 92°15' to 93°15'. The region experiences an annual rainfall of 3180

mm spread across 146 days, with temperatures ranging from 15.1°C to 35.8°C. The average humidity ranges from 75% to 80%. The region is geologically characterized by the presence of alluvial deposits, pebbles, sand, clay, and sporadic laterite formations.



**Fig. 1.** Map showing the stream order of the study area (Cachar district)

## 2.2 Methodology

DEM processing in ArcGIS 10.8.2 includes tasks such as filling, determining flow direction, calculating accumulation, and extracting stream features. Sub-watersheds (SWs) are categorized into high, medium, and low classes based on their morphometric values, which are ranked and assigned Compound Parameter (Cp) values. PCA in SPSS 22.0 reduced 31 morphometric features to 8 essential elements for prioritizing catchments. Every element represents a highly correlated feature. Based on these values, SW features are ranked, given Cp values, and divided into high, medium, and low categories. LULC mapping was conducted at the SW level using Esri LULC 2021, which was derived from Sentinel-2 imagery with a resolution of 10 meters. The categorization was derived from ESRI land cover data and employed to establish priorities for SWs. The SWs were subsequently categorized into high, medium, and low Cp value groups.

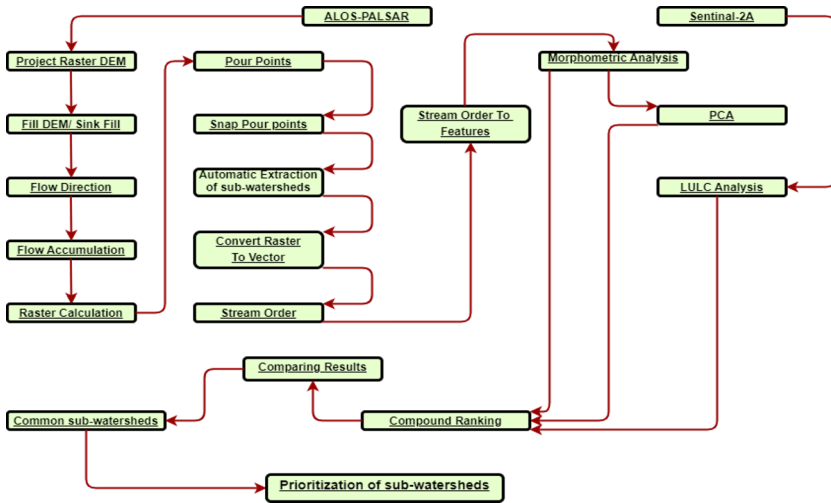


Fig. 2. Map illustrating the methodology flow chart.

### 3 Result

#### 3.1 Linear Parameters

The analysis of watersheds SW\_1 to SW\_6 reveals diverse linear characteristics with potential interdependencies. SW\_5 stands out with the highest stream order (4) and a dense network of 150 streams, indicating complexity. SW\_3 also shows numerous streams (151) but a lower order (3), while SW\_4 has the simplest structure with the lowest order (2) and only 8 streams. In terms of stream length, SW\_3 has the longest total (476.28 km) and moderate mean length (3.15 km), whereas SW\_4 has fewer streams but longer average lengths (6.47 km). SW\_1 and SW\_2 exhibit moderate total stream lengths (102.51 km and 136.19 km, respectively). The bifurcation ratios are high in SW\_5 and SW\_3 (0.993), indicating mature drainage systems, contrasting with SW\_4's lower ratio (0.889), suggesting ongoing network development. Stream length ratios are consistent across watersheds. SW\_1 shows high channel maintenance (3.37), while SW\_4 has the highest mean bifurcation ratio (1.263), indicating less stream branching. SW\_3 has the lowest stream frequency (0.125) and SW\_5 has the highest infiltration number (0.065), indicative of groundwater recharge potential. SW\_4 exhibits the longest overland flow (1.72), whereas SW\_5 shows a dense drainage texture (0.68). Furthermore, drainage intensity is highest in SW\_1 (0.605), and SW\_4 has the highest RHO coefficient (1.263), suggesting significant runoff potential. SW\_3 has the densest stream network (0.393). These findings illustrate how watershed characteristics like stream order, length, and drainage patterns vary, influencing water management strategies and environmental impacts across landscapes.

### 3.2 Aerial Parameters

The six watersheds (SW\_1 to SW\_6) display significant diversity in their aerial characteristics, including basin length, elongation ratio, perimeter, lemniscate ratio, area, form factor, circulatory ratio, and elevation to relief ratio. SW\_5 stands out with a basin length of 50.88 km and an impressive area of 798.995 km<sup>2</sup>, indicating it is a large and potentially influential watershed. In contrast, SW\_4, with a basin length of 21.45 km and an area of 178.044 km<sup>2</sup>, represents a more compact and less extensive watershed. The elongation ratio varies notably, with SW\_3 and SW\_2 being more elongated (Re = 0.878 and 0.871, respectively), enhancing their drainage efficiency. Conversely, SW\_6 has the lowest elongation ratio (0.591), suggesting a more circular shape that could result in slower runoff and potentially higher flood peaks. Perimeter measurements highlight SW\_3 as having the longest perimeter (253.108 km) and SW\_4 the shortest (76.565 km), influencing their runoff volumes and susceptibility to erosion. The lemniscate ratio underscores shape complexity, with SW\_3 exhibiting the highest (605130.785) and SW\_4 the lowest (20479.050), impacting water flow dynamics and flood potentials. SW\_3's expansive area (1210.66 km<sup>2</sup>) indicates a significant regional hydrological impact, contrasting with SW\_4's smaller footprint. The form factor varies significantly, with SW\_3 having the highest (0.606), facilitating quicker runoff, while SW\_6 exhibits the lowest (0.275), indicating slower runoff dynamics. Circulatory ratio ranges from SW\_4's highest (0.381, more circular) to SW\_5's lowest (0.207, more elongated), influencing their runoff patterns and hydrological connectivity. Elevation to relief ratio values are relatively consistent, revealing minor relief differences across these watersheds. These aerial disparities highlight each watershed's unique influence on regional hydrology. Larger, more complex watersheds like SW\_3 and SW\_5 play pivotal roles in regional water dynamics, impacting flood risks, water availability, and ecosystem health in interconnected areas.

### 3.3 Relief Parameters

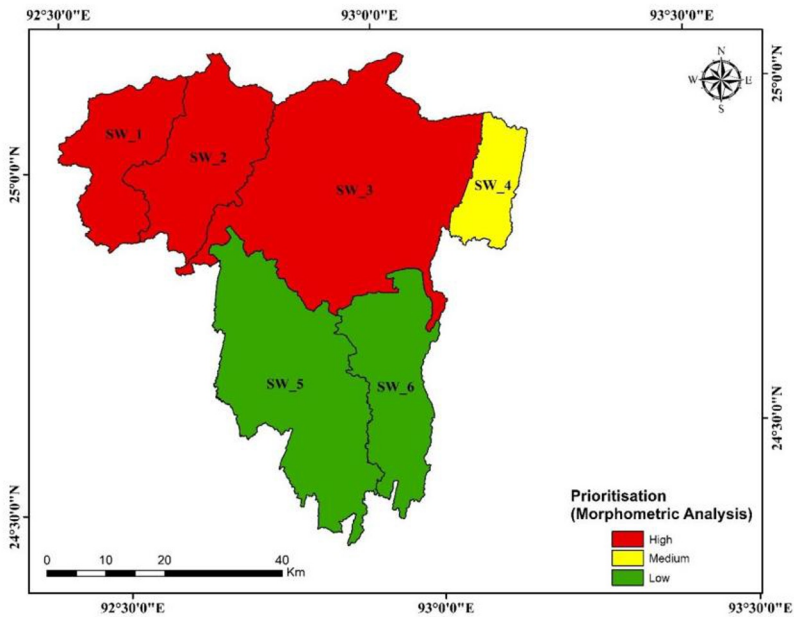
The relief characteristics of the six watersheds (SW\_1 to SW\_6) reveal significant topographical diversity, profoundly influencing their hydrological behaviors and interactions. SW\_3 stands out with the highest maximum elevation (1726 meters) and mean elevation (843.889 meters), indicating substantial elevation changes and a pronounced vertical profile. In contrast, SW\_4 exhibits the lowest maximum elevation (246 meters) and mean elevation (132.528 meters), reflecting a relatively flat terrain. These differences suggest that SW\_3 likely experiences faster water flow and greater erosion potential due to its rugged topography. SW\_3 also shows the highest relative relief (681.922 meters) and overall relief (1714 meters), underscoring significant elevation variations within its boundaries. Conversely, SW\_5 displays the lowest relative relief (188.257 meters) and moderate overall relief (401 meters), indicating more gradual elevation changes. The relief ratio (Rh), which gauges terrain steepness, varies notably among the watersheds. SW\_2 boasts the highest relief ratio (60.824), implying steep slopes that potentially accelerate runoff. In contrast, SW\_5 records the lowest relief ratio (7.881),

suggesting gentler slopes and slower runoff dynamics. Furthermore, the ruggedness number (Rn), combining relief and drainage density, highlights SW\_3 as the most rugged (674.294), indicative of a complex and uneven terrain. Conversely, SW\_4 exhibits the lowest ruggedness number (64.297), signifying a smoother landscape with less ruggedness. These topographical variations significantly influence watershed interactions. SW\_3, characterized by high elevations and rugged terrain, likely contributes to rapid surface runoff and heightened erosion, potentially altering downstream water flow and sediment transport. Similarly, SW\_2's steep slopes may increase runoff rates and flood risks in adjacent watersheds. Conversely, watersheds like SW\_4, with flat terrain and low ruggedness, tend to experience slower runoff and more stable water flow, potentially reducing flood risks but possibly increasing waterlogging and slower groundwater recharge. SW\_5, with gentle slopes, acts as a natural buffer, regulating water flow and minimizing downstream flooding hazards. Overall, the relief characteristics of these watersheds underscore how their topography governs surface water dynamics, groundwater recharge patterns, and regional flood susceptibilities.

### **3.4 Prioritization of Sub Watersheds Based on Morphometric Analysis**

The study employs essential quantitative morphometric characteristics, grouped into linear, relief, and shape categories, to assess sub-watersheds (SWs) susceptible to surface overflow and soil erosion [11,12]. Higher values in relief and linear features denote locations with potentially severe erosion within a basin, ranking SWs accordingly from 1 (highest value) downwards. Conversely, SWs with lower values in shape features, indicating greater susceptibility to erosion, also receive a rank of 1. The Cp value aggregates these ranks for SW1 and divides them by the total features (31), with a consistent approach applied across all SWs.

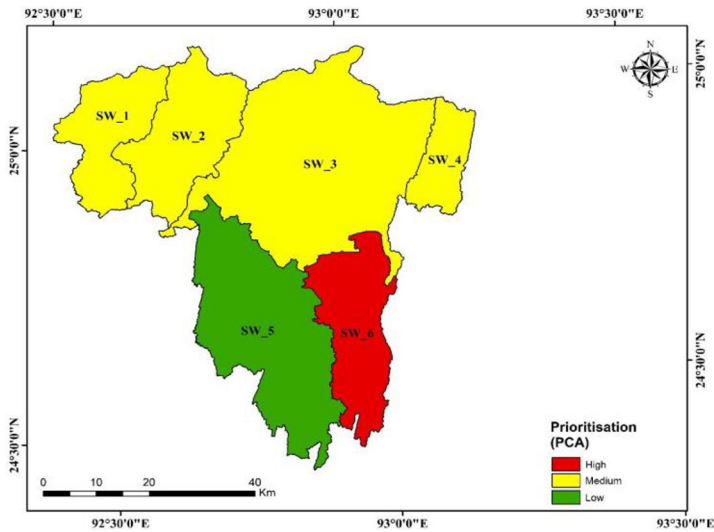
Based on the Cp value categorization, the SWs are classified into three tiers: high (3), medium (3.620689655), and low (3.655172414). Among the evaluated SWs, SW1, SW2, and SW3 are designated as high priority, SW4 as medium priority, and SW5 and SW6 as low. This classification highlights areas at the highest risk of peak flow and soil erosion, emphasizing the need for targeted watershed management strategies in these identified zones



**Fig. 3.** Map illustrating the Prioritization of Sub-watersheds Using Morphometric Analysis.

#### 4 Prioritization of Sub Watersheds Based on PCA

The correlation matrix highlights strong links among hydrological and topographical variables in watersheds, such as Stream Number, Stream Length, and Drainage Density, indicating larger watersheds accommodate more and longer streams. Conversely, Stream Length Ratio correlates negatively with aspects like Channel Maintenance and Drainage Texture complexity as stream lengths relative to other features increase. Elevation metrics like Max Elevation and Relief show positive relationships, with higher Mean Elevation correlating with increased Relief and Relief Ratio, indicating more pronounced relief features in elevated regions. Variables such as Basin Length, Elongation Ratio, and Perimeter provide insights into watershed spatial complexity. The matrix's non-positive definiteness suggests challenges for certain statistical analyses due to multicollinearity. Principal Component Analysis (PCA) distills 31 morphometric features into 8 components, revealing underlying correlation patterns. Cp values derived from PCA categorize sub-watersheds (SWs) into high (3.375), medium (3.5), and low (3.875) priority tiers. SW6 ranks highest, followed by SW1, SW2, SW3, and SW4 in medium priority, and SW5 in the low priority category. This prioritization aids in effective watershed management planning based on comprehensive morphometric assessments.

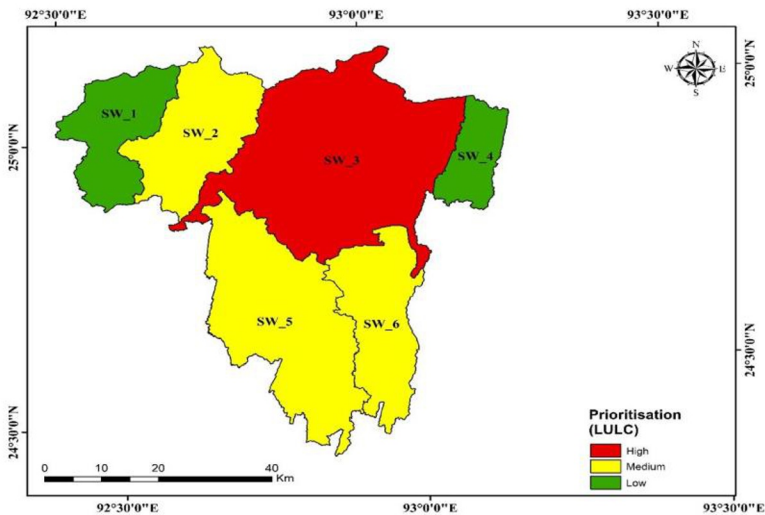


**Fig. 4. Map illustrating the Prioritization of Sub-watersheds Using Principal Component Analysis.**

## 5 Prioritization of Sub Watersheds Based on LULC

Changes in land use have a major impact on environmental change globally by changing the features, intensity, and management of the land. To implement environmentally sound and sustainable water management strategies, it is imperative to comprehend the non-uniform dynamics of land use and land cover[13]. The analysis of sub-watersheds (SW1 to SW6), focuses on various types of land cover and utilization. Water pixels vary from 0.015% in SW4 to 0.212% in SW3. Tree coverage peaks in SW4 at 0.393%, while SW1 exhibits the lowest tree cover at 0.161%. Flooded vegetation pixels are generally scarce, with SW1 reaching the highest at 0.0101%, and SW2 having none. Crop pixels are most prevalent in SW1, constituting 0.624%, and least in SW2 at 0.122%. The percentage of built-up areas ranges widely, with SW6 at 0.476%, the highest, and SW3 at 0.079%, the lowest. Bare ground pixels are minimal across all sub-watersheds, peaking at 0.0068% in SW3 and absent in SW4. Lastly, range land pixels are most significant in SW3 at 0.207% and least significant in SW1 at 0.027%. To conduct compound parameter ranking using the LULC analysis convert the pixels into percentile and then we employ the Weighted Sum Model (WSM) approach. This methodology includes several steps: normalizing the data, assigning weights to criteria, calculating weighted scores, and subsequently categorizing rankings into high, medium, and low tiers. Initially, we normalize the data using the min-max normalization method for each column. The normalization formula adjusts each value based on its minimum and maximum range within the dataset, ensuring uniformity across all parameters. Following normalization, equal weights are assigned to each criterion to simplify the

process. Each normalized value is then multiplied by its respective weight to calculate the weighted scores for every sub-watershed. To rank each feature (parameter) from 1 to 6 for each sub-watershed based on normalized values, we will assign ranks such that the highest normalized value gets a rank of 1 and the lowest gets a rank of 6 for each feature. The compound parameter (Cp) value is calculated by summing the ranks for each sub-watershed and dividing by the seven features. For instance, the Cp value for SW1 is 4.14, obtained by totaling the ranks and dividing by 7. This same process is applied to the other sub-watersheds. The sub-watersheds (SWs) are then classified into three categories based on their Cp values: high priority (2.71), medium priority (3 to 3.86), and low priority (4 to 4.14). Among the 6 SWs, SW3 falls under high priority, SW5, SW6, and SW2 are medium priority, and SW1 and SW4 are low priority. This classification is based on the Land Use/Land Cover (LULC) analysis, displaying the priority levels of the SWs.



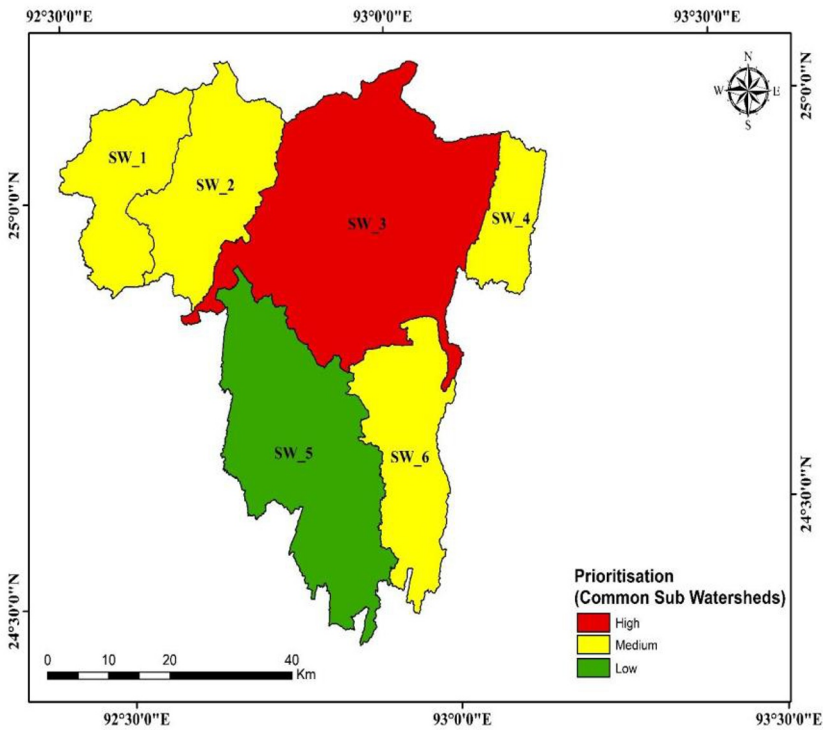
**Fig. 5.** Map illustrating the Prioritization of Sub-watersheds using Land Use and Land Cover.

## 6 Prioritization based on common sub-watersheds

The analysis of sub-watersheds (SW) based on morphometric parameters, principal component analysis (PCA), land use/land cover (LULC), and prioritization reveals distinct characteristics among the six SWs. SW\_1 and SW\_2 demonstrate considerable morphometric potential alongside moderate PCA scores, yet SW\_1 exhibits minimal LULC impact compared to SW\_2, which displays a more moderate influence. SW\_3 stands out for its uniformly high values across all metrics, underscoring its substantial potential for prioritized

management. SW\_4 presents with moderate morphometric and PCA values but registers a low LULC impact, suggesting it may necessitate focused interventions. Conversely, SW\_5 demonstrates consistently low scores across these metrics, implying potential challenges in prioritization. SW\_6, characterized by low morphometric values but elevated PCA and moderate LULC impact, represents a distinctive case requiring tailored strategies for effective management. These evaluations offer a comprehensive basis for informed decision-making in watershed planning and conservation strategies.

To ascertain the sub-watersheds (SWs) sharing common priority levels across morphometric analysis, PCA, and LULC assessments, the results from these three methods were compared. Among them, SW\_3 consistently emerges as a high priority, while SW\_2 and SW\_4 are consistently classified as medium priority. SW\_5 consistently falls into the priority category. Conversely, SW\_1 and SW\_6 exhibit minor discrepancies in their prioritization across the three methods. However, the results are very close, so we prioritize the watershed as in the medium category



**Fig. 6.** Map illustrating the Prioritization of Sub-watersheds of the study area.

## 7 Conclusion

In conclusion, our comprehensive analysis utilizing advanced remote sensing (RS) and geographic information system (GIS) methodologies has provided a detailed understanding of catchment development and its response to hydrological conditions in the Cachar district. Through the examination of 31 morphometric features, 8 principal component analysis (PCA) features, and 7 land use/land cover (LULC) features, we have identified critical priority areas, with SW3 consistently emerging as a top priority across all methodologies. Our findings underscore the importance of targeted soil erosion management strategies in high-priority sub-watersheds (SWs) to mitigate further degradation and promote sustainable land use practices. The integration of physical interventions such as bunds and check dams, alongside biological solutions like vegetative barriers and multipurpose tree plantations, offers effective pathways for conserving soil and enhancing watershed resilience. Moreover, this study serves as a valuable resource for policymakers and water resource managers, offering insights to guide informed decision-making in natural resource management. By leveraging these insights, stakeholders can implement tailored strategies for SW-level planning and management, ensuring the sustainable utilization of resources amidst evolving environmental challenges. Overall, our research contributes to the broader goal of enhancing environmental stewardship and resilience in watershed management, highlighting the critical role of advanced spatial analysis in supporting evidence-based policy and practice.

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