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Watershed Prioritisation for Soil and Water Conservation of Bichhiya River Basin, Central India Using Remote Sensing and GIS

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Abstract

Watershed prioritization has become increasingly important in watershed management, providing many benefits such as soil conservation, groundwater development, and the implementation of artificial recharge schemes. Morphometric analysis is often used to determine watershed priority. This study focuses on the morphometric analysis of the Bichhiya River Sub-basin, Central India to evaluate and understand its hydrological significance. The prioritized watershed is based on morphometric parameters using the Geographic Information System and principal component analysis techniques. ASTER DEM with a 30 meters spatial resolution is used for morphometric analysis as well as the creation of drainage maps. Various parameters, such as linear, areal, as well as relief aspects, are analysed for each sub-watershed. When groundwater and pertinent data sets are insufficient, morphometric analysis is an appropriate technique for conservation of soil and water. The status of each sub-watershed is determined based on these relationships to calculate the final ranking. PCA technique is employed to delineate and analyse morphometric characteristics which may be useful for the conservation of soil and water. Ranks were given to watersheds based on calculated morphometric parameters in terms of soil erosion potential. PCA minimizes the dimensionality of the input data set. The drainage order is 1 to 6, and are divided into six sub-watersheds, labelled sub-watershed I to VI. These sub-watersheds are categorized in various ranks from 1 to 6 based on morphometric analysis using PCA Technique. First rank is given to SW-III, while SW-VI is ranked sixth. So, SW-III should be given high priority for soil and water conservation measures. Studies on the morphometry of the Bichhiya River Sub-basin focused on prioritizing watersheds and correlating morphometric characteristics, highlighting high-priority areas due to significant erosion. The study may be extremely useful for academicians and planners for management of soil conservation, water conservation and groundwater resource development of the area.

Keywords: GIS, DEM, Morphometric analysis, Bichhiya River Sub-basin, Principal Component Analysis, Priority Zone

Introduction

Groundwater is a precious and reliable natural resource that plays a vital role in fulfilling the demand for water supply arising due to inadequate surface water resources throughout the world (Tiwari and Kushwaha, 2018). Watershed management is essential for the conservation of the environment and the sustainable use of water resources. Prioritizing sub-watersheds according to their attributes is a crucial part of managing watersheds, as it helps in resource allocation and conservation effort implementation. Prioritization of watershed is helpful for the conservation of soil and water as well as groundwater development (Tiwari *et al.,* 2016). Morphometric parameters (linear, aerial and relief parameters) allow researchers to examine the condition of a watershed, its hydrological behaviour and propensity for erosion.

Various researchers have demonstrated effectiveness of morphometric analysis in watershed prioritization (Tiwari, 2016; Tiwari, 2017; Tiwari, 2018; Sarino *et al.,* 2019; Sharma *et al.,* 2023; Ali *et al.,* 2024). Subbulakshmi and Nanda (2024) carried out a morphometric analysis to prioritize the sub-watersheds within the Chinar Watershed. In the upper Jhelum sub-catchment of India, Ali *et al.* (2024) prioritized watersheds according to morphometric factors associated with soil erosion risk. Tiwari and Kushwaha (2021) prioritized watershed based on morphometric analysis and principal component analysis technique in Deonar river sub basin, India. Nanda *et al.* (2021) focused on prioritizing watershed in Vishav Kashmir Valley using morphometric and land use criterion. Their study highlighted the importance of integrating morphometric analysis with land use data for holistic watershed management. Sharma *et al.* (2023) used geospatial technologies for watershed prioritization in context of lower Sutlej River Basin for land and water management. A crucial component of effective watershed management and planning is the prioritizing of watersheds using morphometric parameters (Amaliah *et al.,* 2021). Recently morphometric analysis has been used for watershed prioritization various researchers (Ahn and Kim,

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2019; Dinata *et al.,* 2021; Tiwari *et al.,* 2024). A variety of morphological factors, including watershed size, form, slope, stream network, and drainage pattern, are measured and analysed in morphometric analysis (Amaliah *et al.,* 2021). These metrics aid in identifying places that are more vulnerable to erosion, floods, or sedimentation by offering insightful information about the hydrological features and behaviour of the watershed (Sarino *et al.,* 2019).

Ahirwar *et al.* (2019) conducted sub-watersheds prioritization to conserve soil and water in parts of the Narmada River by morphometric analysis using RS and GIS. Their study underscored the importance of incorporating morphometric analysis into flood risk assessment and mitigation strategies. Arefin *et al.* (2020) in their study used PCA technique to prioritize watersheds which is useful in water, and soil conservation. Remote sensing and GIS techniques have proven effective in assessing watershed characteristics and prioritizing sub-watersheds for conservation measures (Manjare *et al.,* 2020). Morphometric analysis of a river basin is a fundamental aspect of geomorphological studies, providing valuable insights into the characteristics and processes of drainage systems (Mani *et al.,* 2022). These measurements include linear, areal, and relief aspects of the basin (Giri *et al.,* 2020). Morphometric analysis plays a crucial role in understanding the geomorphological and hydrological behaviour of a drainage basin (Shrivatra *et al.,* 2021; Shrivastava *et al.,* 2017). By utilizing techniques like GIS, remote sensing (RS) and mathematical calculations, these parameters can be analysed to understand the landform characteristics and hydrological activities within the basin (Joy *et al.,* 2023).

Linking geomorphological parameters associated with the hydrological properties of the basin provides an easy way to interpret the hydrological behavior of various basins (Meshram and Sharma, 2017). Studies on various watersheds in Maharashtra have demonstrated the significance of geospatial techniques in resource management (Varade *et al.,* 2017; Manjare, 2017). For effective watershed management watershed prioritization based on morphometric analysis is very significant. By leveraging quantitative morphometric parameters and integrating various analytical techniques, researchers and policymakers can prioritize sub-watersheds, allocate resources efficiently, and implement targeted conservation actions to ensure the sustainable utilization of water resources and the preservation of watershed ecosystems. The area has been selected for research due to water scarcity during the summer season, as no prior studies have been conducted in this region.

The objectives of the present study are: (a) morphometric analysis of the Bichiya river basin using RS and GIS techniques (b) Prioritization of watersheds using morphometric analysis and the principal component analysis technique (c) identifying the sensitive areas that need to be prioritised for soil and water conservation; (d) identifying the correlation between all parameters used in watershed prioritization (e) suggesting measures for soil and water conservation.

Study Area

The proposed study area is part of central India and comes under Survey of India toposheets no. 63H/6, 63H/7, 63H/10, as well as 63H/11, on a scale of 1:50,000 and lies between 24°20'29.36" to 24°35'20.23" N latitude and 81°17'18.76" to 81°44'50.29" E longitude centre. It is bounded an area of about 575 km^2. The climate of region is sub-tropical.

The Bichhiya River Basin is situated in the northeast region of Madhya Pradesh, central India. At an elevation of approximately 410 meters above mean sea level, the Bichhiya River rises from Kaimur Hill, which is located 3 kilometers south of Kankeshra Village in Mauganj Tehsil of Mauganj District. The river then flows south-westward, joining tributaries such as Devdah Nala, Sannai Nala, Saba Nala, Marachwar Nala, Dudhania Nala, and Juda Nala, among others. The Bichhiya Rivers only get runoff from rainfall, and only flows well during the monsoon season. The rest of the year, the river has very little flow. This river rises in sandstone and passes through limestone, alluvial deposits, and shales. Separately, the Bichhiya River travels about 55 km to reach the Bihar River, close to Rewa Fort. The majority of the Bichhiya River's structure is dendritic. It comprises the south-west expansion of the Upper Vindhyan supergroup.

The catchment's hydrological characteristics are shown by the quantitative morphometric measures. The various morphometric including perimeter area, were calculated using the suggested formula for the quantitative examination of morphometric features of the study area (Table 1-2). Morphometric analysis was employed to select sub-watersheds by looking at several parameters, such as the basin's linear aspect, aerial aspect, and relief aspect (Bichhiya River Basin). The patterns of the drainage were studied mainly on the topographical map, on a 1:50,000 scale. On studying the regional picture of area from the topographical map, it becomes apparent that the courses of the Bichhiya and other streams are markedly controlled by structural and lithological elements, which is evident in several naalas like the Gurhwa, Devdah, Shannai, Juda, Pakariya, and Shaba Nala, which meet the Bichhiya after generally flowing in a north-east direction (Fig. 1).

Methodology

Morphometric parameters from the ASTER 30 m DEM drainage network are visualized and analyzed in GIS environment. The Aster DEM was changed to the Universal Transverse Mercator (UTM) Zone 44 North projection system for the study area. Elevation details of the study area were obtained using the ASTER DEM and drainage overlay to depict the continuous anomaly in topography (Fig. 2). Various morphometric parameters were calculated as per standard method. Morphometric parameters are correlated using principal component technique. PCA reduces the dimensionality of the data by identifying the most influential morphometric variables for prioritization.

Results

Basic Parameters of River Basin

Area of the WS (Watershed) (A)

The catchment of the Bichhiya river basin may accurately represents the total amount of water. The entire area is projected on a horizontal plane with a gentle slope, making it the most essential aspect. The total area is 575 km^2. Watersheds with largest and smallest area are 182.97 km^2 (SW-VI) and 53.71 km^2 (SW-I), respectively.

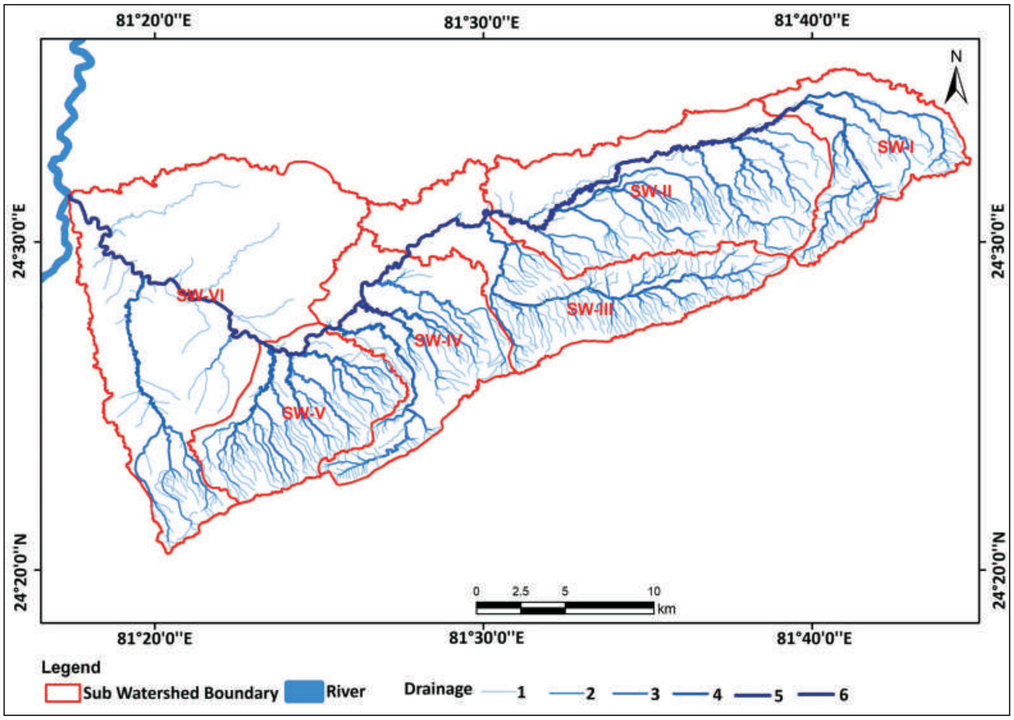

Fig.1. Sub watersheds map of the study area

The perimeter WS (P)

It is the border that surrounds its area. The watershed's whole circumference measures 418.18 km. The Bichhiya River Basin's largest and smallest sub-watershed perimeters are 95.35 km (SW-VI) and 43.50 km (SW-V), respectively.

Linear Aspects

Stream order (U)

Horton (1945) was the first to promote stream ordering systems; however, Strahler (1952) modified this ordering method. According to Strahler's technique, the author has implemented the stream ordering (Fig.1; Table 1). The identification of stream order, which illustrates the relative and hierarchical relationships between stream segments, their connectedness, and the discharge having contributions from the main watershed and its sub-watersheds, is the first stage in drainage basin analysis. As a result of the network of different tributaries and its main stream flowing along the general slope direction, which in turn is well adhered to the corresponding geological features, the total drainage of the Bichhiya Basin area encompasses dendritic and parallel patterns. It is observed that first-order streams exhibit the largest frequency, and the frequency of the stream decreases as stream order increases.

Stream Number (Nu)

The order number and the stream segment numbers ultimately form an inverse geometric sequence (Horton, 1945). This is a numerical evaluation of the stream branching complexity within a watershed (Horton, 1945). Among these characteristics, slope is critical to the formation of streams in the watershed, since most first-order streams originate from ridges and hills with steeper slopes, while second-order streams form downstream, and so on. The total number of streams for sub-watersheds I, II, III, IV, V, and VI are 107, 165, 177, 129, 154, and 85, respectively (Table 1). Thus, the entire watershed has 817 streams. The watershed in all six sub-watersheds is characterized by a relatively lower number of higher-order streams and a higher number of first-order and second-order streams, which constitute 89% (SW-IV) to 94% (SW-VI) of total streams in the sub-watersheds. The higher number of first-order and second-order streams in sub-watershed II (Table 1) signifies the larger area of steeper slopes and associated with higher runoff, intense erosional processes, lower infiltration, and lower permeability. In contrast to this, the percentage of area occupied by steeper slopes is comparatively low in the SW-VI, hence the smaller number of first-order and second-order streams. SW-III (131) has the highest first order, whereas SW-VI has the lowest first-order streams (67).

Stream Length (Lu)

The total stream lengths in all six sub-watersheds are essentially contributed by the stream lengths of the first-order and third-order streams, which constitute 64.95% of the total stream length in sub-watersheds I and 69.66%, 78.57%, 64.70%, 75.22%, and 69.63%, respectively, in sub-watersheds II to VI. The total stream length of sub-watershed II (210.34 km) is about 2 times higher than the total stream length of sub-watershed I (100.39 km; Table 1). This is explicable in terms of infiltration and permeability, which are lower in SW-II and hence the higher stream lengths, and vice versa in the case of SW-I. Stream lengths that are different from other streams of the same order in the basin have normal lengths. Furthermore, the usual length of streams is of the first order in first-term mathematical arrangements. Longer stream lengths are typically found at the lower inclines, whereas shorter stream lengths are typically found on higher, steeper slopes.

Mean Stream Length Ratio (Lsm)

The average length of streams gives information about the length of streams per number of streams. The differences in the average length of streams among the stream orders appear to be caused by the distribution of the number of streams along with their lengths in the order of streams, according to the occurrence of surface rock permeability with respect to topography. It indicates that stream length is directly proportional to stream number which increases due to development of drainage networks because of topography and surface rock permeability.

A close examination of Table 1 reveals that the average stream lengths of the first to fourth order and six order streams in SW-VI are significantly higher as compared to the other five sub-watersheds of the basin. This is very important as the higher infiltration and higher permeability of the sub-watershed VI are expected to favour lower average stream lengths for stream orders. This deviation can be attributed to the gentle slope, which forms a larger part of SW- VI, as the gentle slope or gradient makes branching of streams less effective and each stream joins the other stream at a greater distance. This is very evidently seen in the first-order streams defining the sub-parallel drainage pattern (Fig. 3). A visual inspection of figure 3 reveals that these are the longest first-order streams in the entire catchment.

Stream Length Ratio (Rl)

The average length of streams of a given order to the average length of streams of the next lowest order within the drainage basin is characterised by Stream Length Ratio (Rl) (Horton, 1945). To understand the relationship between the discharge of surface flow and the erosional stage of a basin, the stream length ratio (Lr) evaluates the relative rock permeability in the basin. Rl of 4^{th} order streams of SW-II shows a high value of 4.14 compared to 1^{st} streams (0.17) in SW-VI. The fourth-order streams indicate that they flow through the rocks of high rock permeability in SW-II; the first-order streams (SW-VI) reflect that they run through the area of low permeability in the rock surfaces; and the other all-order streams infer that they flow where there is a medium rock permeability in the entire sub-watershed (Table 1).

Bifurcation Ratio (Rb)

The number of stream network branches is used to calculate the bifurcation ratio (Horton, 1945). The number of stream segments in a particular order, divided by the number of segments in the next higher order, is known as the bifurcation ratio. It provides information on the watershed's structure and the behaviour of runoff. The average bifurcation ratios for the sub-watershed are SW-I (3.10), SW-II (3.50), SW-III (4.40), SW-IV (2.69), SW-V (3.27), and sub-watershed VI (4.16) (Table 1). The average bifurcation ratio is less than 4, which indicates insignificant structural control. Thus, bifurcation ratio indicates the presence of geomorphological control and absence of structural control on the drainage evolution of a catchment.

Mean Bifurcation Ratio (Rbm)

To arrive at a more accurate bifurcation number, Strahler used a weighted average ratio of bifurcation, which was calculated by multiplying the ratio of bifurcation for each successive set of patterns and streams occupied in the ratio. SW-III and SW-VI have higher and lower values, respectively.

Aerial Aspects

Drainage Density (Dd)

It is calculated by dividing the total length of stream by the area of the basin. It is calculated separately for all the sub-watersheds and given (Table 2). The nature of bed rock and overburden are the important features which controls drainage density. In highly permeable rocks, the value of drainage density will be low because of less runoff, and in areas of clay and shales, it will be highest (Giri *et al.*, 2020). Thus, it is obvious that the highest drainage density (2.78) of the SW-III is due to low porosity and permeability of Upper Rewa Sandstone, which is mostly a hilly area. Lowest drainage density (0.88) of the SW-VI is because of 0 high infiltration, porosity, and permeability, consequent to karstification, joint patterns, etc., of the underlying limestones.

Stream Frequency (Fs)

The number of streams per unit area indicates stream frequency (Horton, 1945). The stream frequency for SW-VI 0.47 indicates fine texture, and SW-V 2.39 bears highest value, which indicates course texture.

Drainage Texture (T)

The total number of stream orders inside the basin's perimeter is taken into account by the drainage texture (Horton, 1945). In study area, drainage texture has the largest value at SW-V and the lowest at SW-VI, indicating that rate of infiltration is high in SW-V, where it is low because of the low permeability of the rock surfaces.

Form Factor (Rf)

The dimensionless ratio of the basin's area to its length squared is known as Rf (Horton, 1933). The 0values of the form factors are 0.34, 0.30, 0.32, 0.32, 0.33 and 0.29 for sub-watersheds I, II, III, IV, V, and sub-watershed VI, respectively (Table 2), indicate elongated shapes of the sub-watersheds. Sub-watershed III is comparatively slightly more elongated.

Circulatory Ratio (Rc)

The diameter of a circle equal to the circumference of the basin is its Rc. The features which affect the watershed stream length, stream frequency, the geological characteristics (such as joints, folds, fractures, foliation, and faults), the land use and cover, the temperature, the relief, and the slope. A high circulatory ratio indicates the dendritic stage of a watershed. In the tributary watershed, the low, medium, and high amounts of Rc represent the young, maturity, and old life stages, respectively. The value of Rc ranges from 0.13 to 0.43.

Elongation Ratio (Re)

It is the ratio of the maximum basin length to the diameter of a

Table 1: Linear aspect of the Bichhiya River Basin

Sub Watershed (SW)	Stream Order					
	I	II	III	IV	V	VI
SW-I						
No. of stream	78	21	5	2	1	0
Stream length (Lu)(km)	47.31	17.90	22.68	10.83	1.68	0
Mean stream length(km) (Lsm)	0.61	0.85	4.54	5.42	1.68	0
Stream length ratio(km) (Rl)	0.37	1.26	0.47	0.15	0	0
Bifurcation Ratio (Rb)	0	3.71	4.2	2.5	2	0
Mean Bifurcation Ratio (Rbm)	3.10					
SW-II						
No. of stream	121	31	10	2	1	0
Stream length (km)	96.61	49.91	32.41	6.11	25.30	0
Mean stream length(km) (Lsm)	0.79	1.61	3.24	3.05	25.3	0
Stream length ratio(km) (Rl)	0.51	0.64	0.18	4.14	0	0
Bifurcation Ratio (Rb)	0	3.9	3.1	5	2	0
Mean Bifurcation Ratio (Rbm)	3.5					
SW-III						
No. of stream	131	35	9	1	1	0
Stream length (km)	113.18	27.34	13.49	17.81	7.03	0
Mean stream length(km) (Lsm)	0.86	0.78	1.48	17.81	7.03	0
Stream length ratio(km) (Rl)	0.24	0.49	1.32	0.39	0	0
Bifurcation Ratio (Rb)	0	3.74	3.88	9	1	0
Mean Bifurcation Ratio (Rbm)	4.40					
SW-IV						
No. of stream	91	24	8	3	2	1
Stream length (km)	65.38	27.65	23.36	16.53	8.18	2.69
Mean stream length(km) (Lsm)	0.71	1.15	2.92	5.51	4.09	2.69
Stream length ratio(km) (Rl)	0.42	0.84	0.70	0.49	0.32	0
Bifurcation Ratio (Rb)	0	3.79	3	2.66	1.5	2
Mean Bifurcation Ratio (Rbm)	2.59					
SW-V						
No. of stream	105	35	10	3	0	1
Stream length (km)	93.88	41.00	21.79	17.66	0	4.99
Mean stream length(km) (Lsm)	0.89	1.17	2.17	5.88	0	4.99
Stream length ratio(km) (Rl)	0.43	0.53	0.81	0	0	0
Bifurcation Ratio (Rb)	0	3	3.5	3.33	0	0
Mean Bifurcation Ratio (Rbm)	3.27					
SW-VI						
No. of stream	67	13	3	1	0	1
Stream length (km)	88.31	15.79	12.97	13.54	0	18.89
Mean stream length(km) (Lsm)	1.31	1.21	4.32	13.54	0	18.89
Stream length ratio(km) (Rl)	0.17	0.82	1.04	0	0	0
Bifurcation Ratio (Rb)	0	5.15	4.33	0	0	0
Mean Bifurcation Ratio (Rbm)	2.37					

circle with the same area as the basin (Schumm, 1956). Because precipitation delivered during a storm in highly elongated basins must traverse a broad range of lengths to reach the basin outflow, in contrast to catchments that are more circular, the elongation ratio has significant hydrological implications.

The elongation ratio (Re) is a significant index in the analysis of watershed shape, which helps in giving an idea about the hydrological character of drainage in a basin. The values of the elongation ratio vary from 0.6 to 0.66, which indicates less elongation due to the high relief and steep ground slope. Higher value of re indicates higher infiltration rate, less runoff and low soil erosion in the area (Arefin *et al.,* 2020).

Drainage Intensity (Di)

Drainage intensity is significant parameter in watershed prioritization and it is ratio of stream frequency to drainage density. Drainage intensity provides an indication of the effectiveness of drainage density as well as stream frequency on runoff of a watershed (Shekar and Mathew, 2022). The higher value of Dd indicates a significant influence of these factors on surface runoff (Singh *et al.,* 2021). The significance of these parameters is determined by their importance with respect to soil erosion, with a higher weightage given to parameters that have a direct impact on soil erosion (Singh *et al.,* 2021; Shekar and Mathew, 2022). Drainage intensity (Di) in the Bichhiya Basin ranges from 0.57 to 1.07 and is higher and lower at SW I and SW VI, respectively.

Length of overland Flow (Lo)

Schumm asserts that the overland flow's length is constant from greatest to lowest and highest value denoting a larger surface runoff and lowest value a shorter one. It is highest in SW-VI (0.61) and lowest in SW-V (0.18). It indicates that in SW-VI, stream travels about 600 m to meet main stream while at SW-V, it is shorter.

Infiltration Number (If)

According to Faniren (1968), it is defined as the combination of stream frequency and drainage density. Infiltration number value varies from 6.66 (SW-V) to 0.38 (SW-VI) (Table 2). Based on study, SW-V is less likely to experience surface runoff and erosion, whereas SW-VI is more susceptible to surface runoff, erosion, and potentially flooding.

Constant of Channel maintenance (C)

The catchment surface requirement for one unit of route length is specified by this characteristic. Schumm (1956) made the initial suggestion and described it as the opposite of drainage density. It is area needed to maintain one foot of drainage channel. The computed constant of channel maintenance values for SW-I to SW-VI are 0.53 km^2/km, 0.55 km^2/km, 0.48 km^2/km, 0.51 km^2/km, 0.36 km^2/km and 1.22 km^2/km, respectively (Table 2). These indicate that SW-VI has a larger value of C than other five sub-watersheds, which demonstrate low C. This describes that rock permeability in the SW-V is lower than in SW-VI, where the rock surfaces have a higher permeability.

Relief Aspects

Basin Relief

The elevation difference between the highest and lowest points of the valley floor is known as basin relief. It establishes the slope, which affects runoff and the movement of silt. The value is represented in Table 2 for the sub-watershed of Bichhiya River Basin. It is highest in SW-VI (395 m) and lowest in SW-I (181 m).

Relief Ratio (Rr)

It is the ratio of the maximum basin relief to the horizontal distance along the longest dimension of the basin parallel to the principal drainage line (Schumm, 1956) and used to understand the geomorphological processes and evolution of a basin. It indicates overall steepness of a basin, which is an important parameter for erosion processes operating on the slope of basin. The relief ratio of SW-V (27.97) is 2.63 times higher than that of the SW-II (10.65; Table 2). These values indicate steeper slopes and higher intensity of erosion in the SW-V.

Ruggdness Number (Rn)

The slope steepness and length are combined to create ruggedness number (Rn), which has an impact on erosion potential as well as structures of landforms. It is a result of the drainage intensity (Di) and basin relief (Strahler, 1958). Rn measures the combined effect of local terrain and the magnitude of drainage density. Several studies have utilized the ruggedness number to evaluate erosion potential and hydrological characteristics of watersheds (Shekar and Mathew, 2022). Rn represents the relationship between relief, drainage density as well as structural complexity of the terrain. The ruggedness number of SW-V (1.09) is 3.04 times higher than SW-VI (0.32; Table 2), indicating high relief and steep slopes.

Table 2: Morphometric Analysis of Bichhiya River Basin

	SW-I	SW-II	SW-III	SW-IV	SW-V	SW-VI
Basic parameter						
Basin Area (A) (km^2)	53.71	115.16	85.6	73.75	64.41	182.38
Perimeter (P) (km)	54.82	68.23	89.53	66.75	43.5	95.35
Basin Length (Lb) (km)	12.61	19.44	16.43	15.09	13.98	25.24
Areal Aspects (Aa)						
Drainage Density (Dd)	1.87	1.83	2.09	1.95	2.78	0.82
Stream Frequency (Fs)	1.99	1.43	2.07	1.75	2.39	0.47
Texture ratio (T)	1.95	2.42	1.98	1.93	3.54	0.89
Form Factor (Rf)	0.34	0.30	0.32	0.32	0.33	0.29
Circulatory Ratio (Rc)	0.22	0.31	0.13	0.21	0.43	0.25
Elongation Ratio (Re)	0.66	0.62	0.64	0.65	0.65	0.60
Compactness Constant (Cc)	2.09	1.78	2.71	2.18	1.52	1.98
Drainage Intesity (Id)	1.07	0.78	0.99	0.90	0.86	0.57
Length of overland flow (Lo)	0.27	0.27	0.24	0.26	0.18	0.61
Infiltration Number (If)	3.72	2.62	4.32	3.41	6.66	0.38
Constant of Channel maintenance (C)	0.53	0.55	0.48	0.51	0.36	1.22
Relief Aspects						
Basin Relief (R)	181	207	220	338	391	395
Relief ratio (Rr)	14.36	10.65	13.39	22.39	27.97	15.65
Ruggdness Number (Rn)	0.34	0.38	0.46	0.66	1.09	0.32

Soil

Soil plays a crucial role in watershed prioritization by influencing erosion, water retention, and land stability (Arefin *et al.,* 2020). Soil porosity and permeability control groundwater and surface water infiltration, aiding in quantifying groundwater and selecting suitable sites for recharge basins. The type of soil and its thickness in the basin affect the capacity of the groundwater to recharge. The soil in this area has a loose texture and strong capillary action and percolation qualities that allow for groundwater recharging. Red gravel throughout the study area, it is common to find mixed with yellow and red soils. A soil map is prepared using visual analysis of the Landsat 8 satellite data collected in the region (Fig.4).

Geology

Geology influences watershed prioritization by shaping drainage patterns, soil stability, and water flow (Giri *et al.,* 2020).). Geology of the parent rock affects water flow and availability through its porosity, permeability, and weathering, making it a critical factor in watershed prioritization Kalyani and Muni Reddy, 2023). Drought and groundwater issues are quite prevalent in the research area, especially in the summer season. To comprehend aquifer flow and rocks, the fundamental geology map was applied. The lithounits of basin area are Jhiri Shale, Ganurgarh Shale, Upper Rewa Sandstone, and Nagod Limestone (Fig.5). The research area is located in part of the Pre-Cambrian Sedimentary groundwater province in Central India. The majority of the rocks are sandstone and shale from the Vindhyan Supergroup. Figure 5 depicts a lithology map of the area. The presence and movement of groundwater are controlled, on a local scale, by the fractured and well-jointed sandstones.

Watershed Prioritization

Watershed prioritizing deals with arranging different sub-watersheds within a catchment according to priority in which they

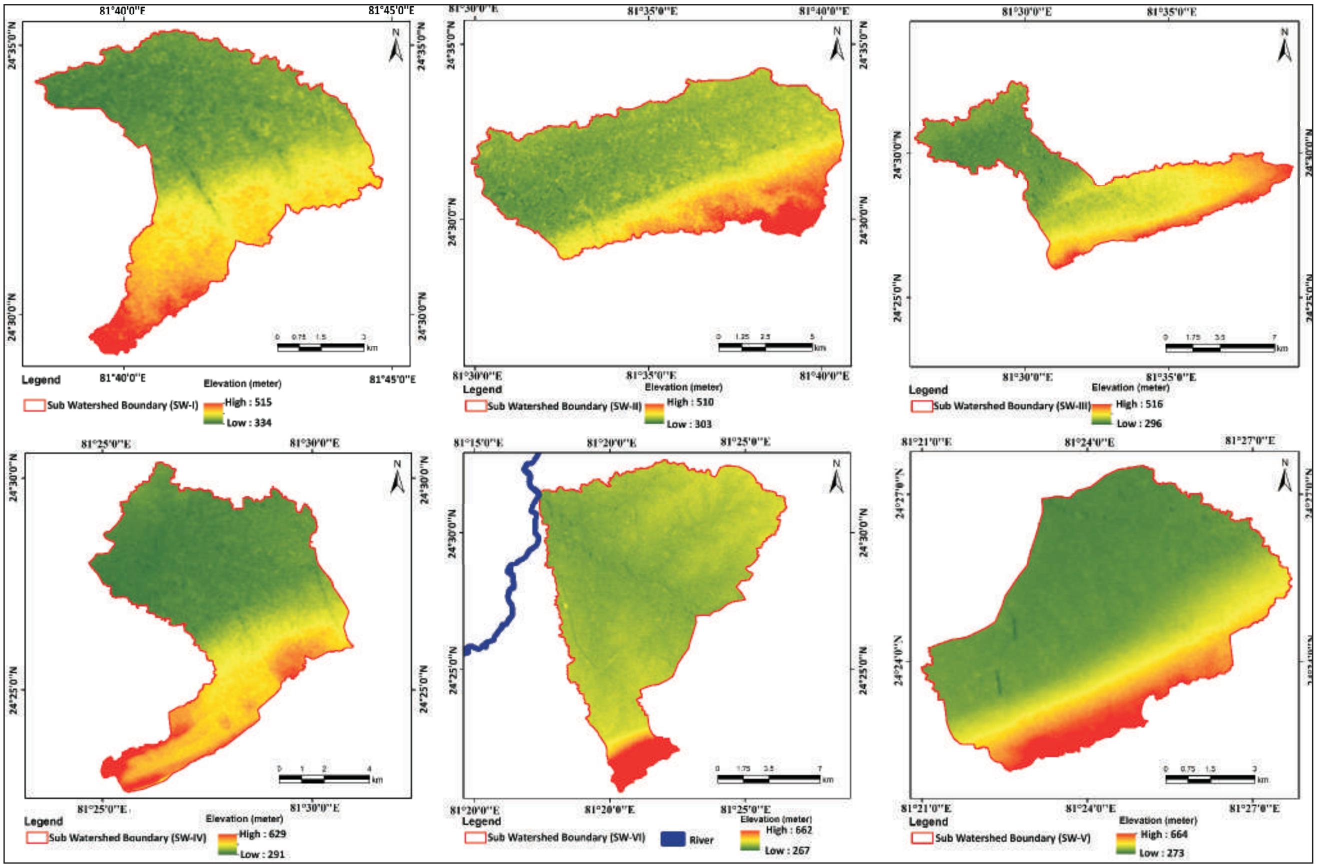

Fig.2. Digital elevation model view of sub-watershed

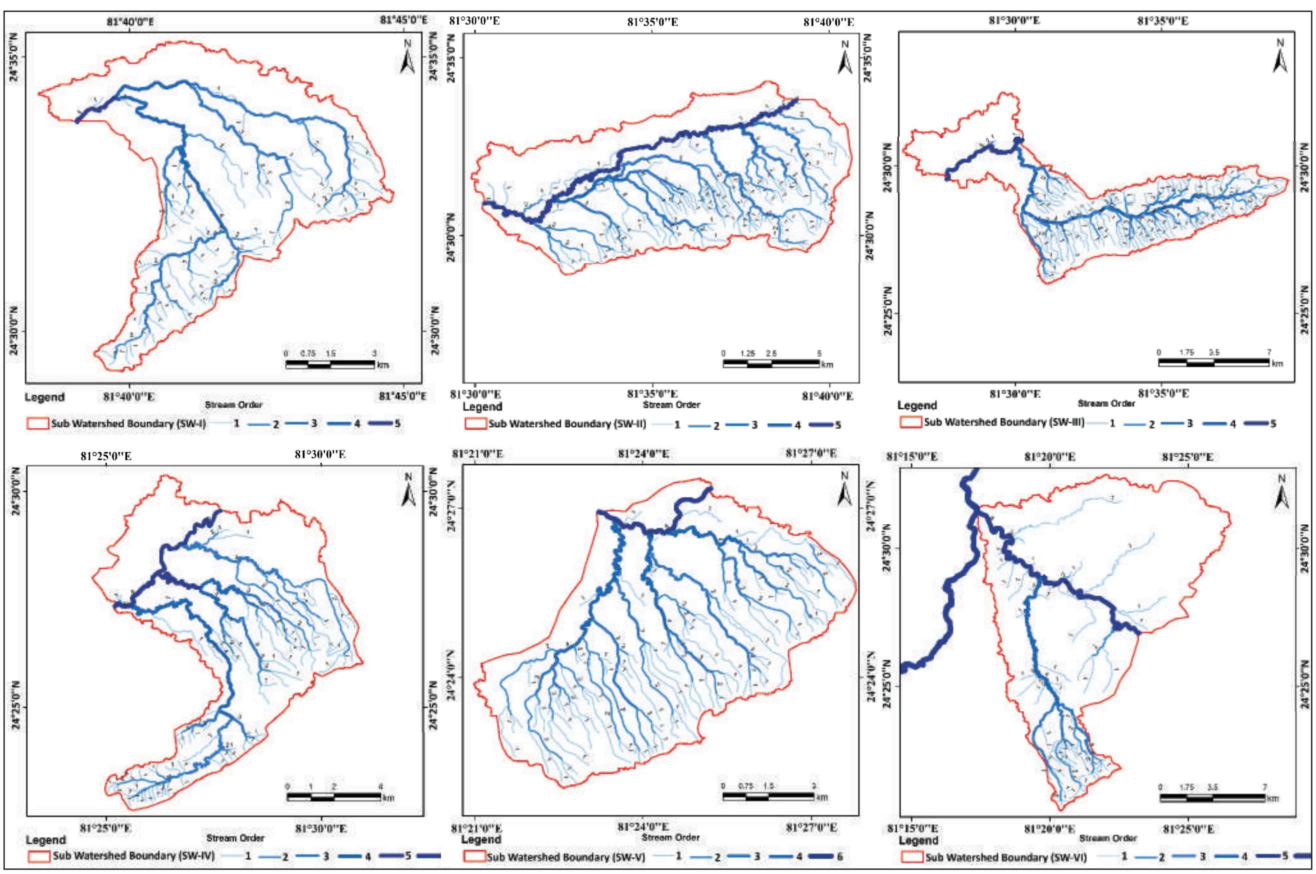

Fig.3. Drainage order map of sub watershed area

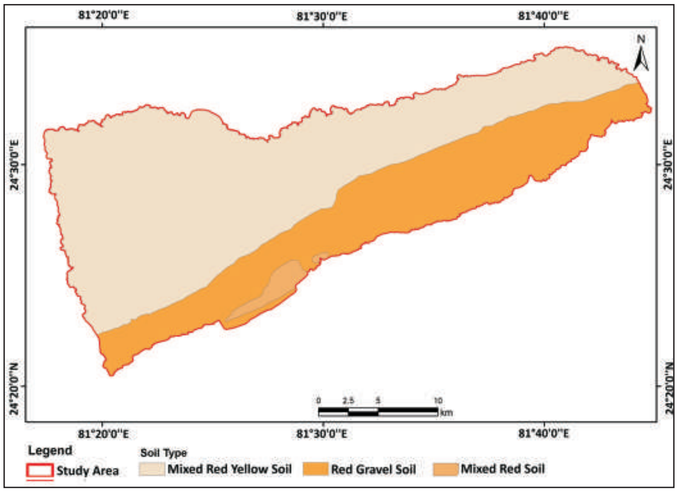

Fig.4. Soil map of sub watershed area

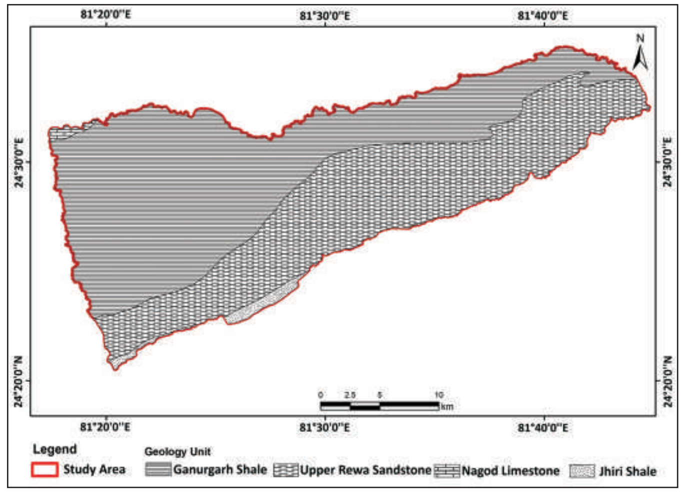

Fig.5. Geology map of sub watershed area

should be addressed and subjected to soil conservation. To ensure sustainable development through effective management as well as planning of natural resources, it is necessary prioritize the watersheds within drainage basin. Watershed prioritization using morphometric analysis integrates GIS and PCA for effective sub-watershed management and prioritization strategies (Govarthanambikai and Sathyanarayan, 2024). The intercorrelation matrix of the geomorphological parameter (Table 3). Total variance, unrotated matrix, and rotated matrix are derived using SPSS 26.0 software and (Table 4-5). The composite values of 13 geomorphic parameters for Bichhiya River Sub-basin are calculated, and priority rank is represented in Fig. 6 and Table 6.

For getting the intercorrelations among various geomorphic parameters, a relationship framework is obtained utilizing the SPSS 26.0 program. The relationship lattice of different geomorphic parameters of the Bichhiya Watershed (Table 3) indicates that the diagonal elements are always 1 because each parameter is perfectly correlated with itself. Off-diagonal elements represent the correlation coefficient between pairs of parameters. Values closer to +1 or -1 indicate a strong positive or negative correlation, respectively, while values closer to 0 indicate a weak correlation. C and Lo (1.00) indicate that they are almost perfectly correlated. Drainage density and infiltration number (0.98) are highly correlated, suggesting information regarding the hydrogeological features of basin. The form factor Rf and elongation ratio (0.98) are highly correlated, indicating that they describe similar aspects of basin shape. C and Dd (-0.93) are strongly negatively correlated, meaning that as one increases, the other decreases. C and Fs (-0.95) are also strongly negatively correlated indicating similar results.

Principal Component Analysis (PCA)

It is a powerful statistical technique that is useful in watershed prioritization of any basin. PCA transforms a set of correlated variables into a few uncorrelated variables called principal components (Farhan *et al.,* 2017). This dimensionality reduction helps to recognize the most influential morphometric parameters for watershed prioritization. PCA based prioritization provides a more effective and targeted approach to watershed management compared to using all morphometric parameters (Meshram and Sharma, 2017).

It is evident from Table 4 for component, 1 the initial eigenvalue is 8.18. This explains 62.92% of the total variance, indicating it captures most of the information in dataset. The rotation eigenvalue is 7.57. After rotation, it still explains a significant portion (58.24%) of variance. It also explains majority of variance, capturing the primary structure of data. The initial eigenvalue of component 2 comes out 3.01. This describes 23.14% of variance, making it the second-most important component. The rotation eigenvalue is 3.13. After rotation, it explains 24.10% of

Table 3: Intercorrelation matrix of the geomorphological parameter of Bichhiya Watershed

Correlation Matrix	R_r	R_c	C_c	C	D_d	D_i	R_e	R_f	I_f	R_{bm}	L_o	F_s	T
R_r	1.00	0.53	-0.44	-0.31	0.56	0.01	0.37	0.51	0.61	-0.32	-0.31	0.42	0.55
R_c	0.53	1.00	-0.96	-0.16	0.39	-0.32	0.00	0.17	0.37	-0.22	-0.15	0.14	0.68
C_c	-0.44	-0.96	1.00	0.01	-0.19	0.40	0.05	-0.09	-0.16	0.45	0.00	0.04	-0.50
C	-0.31	-0.16	0.01	1.00	-0.93	-0.78	-0.82	-0.84	-0.87	-0.58	1.00	-0.95	-0.82
D_d	0.56	0.39	-0.19	-0.93	1.00	0.62	0.74	0.83	0.98	0.50	-0.94	0.95	0.93
D_i	0.01	-0.32	0.40	-0.78	0.62	1.00	0.90	0.83	0.62	0.53	-0.78	0.83	0.37
R_e	0.37	0.00	0.05	-0.82	0.74	0.90	1.00	0.98	0.75	0.23	-0.83	0.88	0.56
R_f	0.51	0.17	-0.09	-0.84	0.83	0.83	0.98	1.00	0.85	0.22	-0.85	0.91	0.69
I_f	0.61	0.37	-0.16	-0.87	0.98	0.62	0.75	0.85	1.00	0.48	-0.88	0.95	0.89
R_{bm}	-0.32	-0.22	0.45	-0.58	0.50	0.53	0.23	0.22	0.48	1.00	-0.57	0.56	0.37
L_o	-0.31	-0.15	0.00	1.00	-0.94	-0.78	-0.83	-0.85	-0.88	-0.57	1.00	-0.95	-0.82
F_s	0.42	0.14	0.04	-0.95	0.95	0.83	0.88	0.91	0.95	0.56	-0.95	1.00	0.79
T	0.55	0.68	-0.50	-0.82	0.93	0.37	0.56	0.69	0.89	0.37	-0.82	0.79	1.00

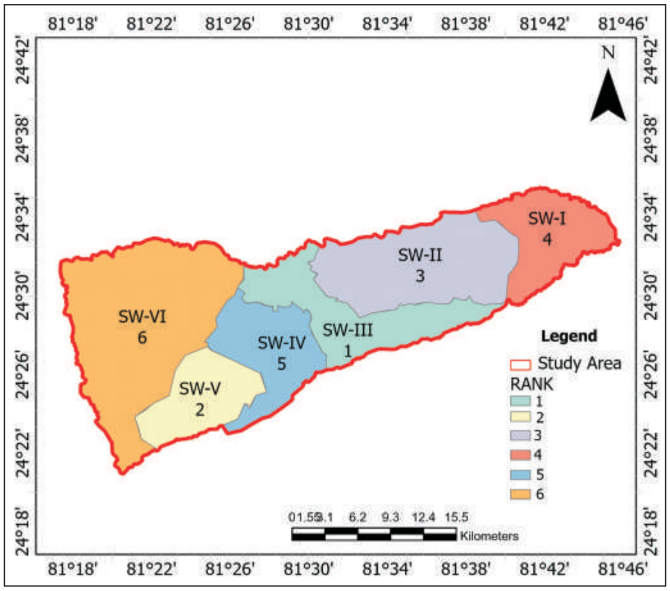

Fig.6. Watershed prioritization map of the study area

variance. It adds additional detail, capturing aspects of data not explained by component 1. Regarding component 3, the initial eigenvalue is 1.13. It explains 8.68% of variance. The rotation eigenvalue is 1.61. After rotation, it explains 12.40% of variance. This further refines the model by explaining the remaining variance.

The first three components explain 94.74% of total variance after rotation, indicating that nearly all the variability in the data can be captured by these three components. Components beyond the third contribute very little to the explanation of variance (less than 5% each), indicating they are less significant.

As evident from Table 5, component 1 is strongly positive on variables related to the density and frequency of drainage networks and negatively on variables related to length of over land flow (Lo) and C is weighted. It suggests that component 1 represents the overall drainage density and efficiency flow of water in basin. Component 2 has high positive loadings on RC and RR, which are related with watershed and relief. It has strong negative loading on Cc. This suggests that component 2 represents the geometric shape and relief of the watershed, indicating a more circular and high-relief watershed. The component 3 is moderately loaded on form factor, elongation ratio, and relief ratio, with high negative loadings on average bifurcation ratio. It indicates that Component 3 captures aspects of watershed and bifurcation patterns, suggesting variability in the branching structure of the drainage network. It accurately depicts shapes and bisection patterns.

Rotation makes a difference in making the interpretation simpler by maximizing the loadings of each variable on a single component, which results in a more articulated relationship between the factors and the components. Component 1 primarily covers the density and structural features of basin. High scores in this component indicate well-developed and dense drainage networks in watershed with high loadings on FS, DD, Lo, RF, Re, and T. The negative loadings on C and IF suggest that watersheds with higher values have less dense networks. The geometric configuration and relief features belong to component 2. Watersheds with higher scores in this component are likely more compact and have greater relief ratios. They also have more intense drainage because of

Table 4: Total variance explained of Bichhiya Watershed

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	8.18	62.92	62.92	8.18	62.92	62.92	7.57	58.24	58.24
2	3.01	23.14	86.07	3.01	23.14	86.07	3.13	24.10	82.34
3	1.13	8.68	94.74	1.13	8.68	94.74	1.61	12.40	94.74
4	0.54	4.14	98.88						
5	0.15	1.12	100.00						
6	0.00	0.00	100.00						
7	0.00	0.00	100.00						
8	0.00	0.00	100.00						
9	0.00	0.00	100.00						
10	0.00	0.00	100.00						
11	0.00	0.00	100.00						
12	0.00	0.00	100.00						
13	0.00	0.00	100.00						

Table 5: Unrotated matrix and Rotated matrix

Component Matrix	Component			Rotated Component Matrix	Component		
	1	2	3		1	2	3
Stream Frequency (Fs)	0.99	-0.13	-.--	Stream Frequency (Fs)	0.98	-.--	-0.13
Drainage Density (Dd)	0.97	0.13	-0.13	Drainage Density (Dd)	0.97	-.--	-0.15
Length of overland flow (Lo)	-0.96	0.13	0.10	Length of overland flow (Lo)	0.96	-.--	0.24
Constant of Channel maintenance (C)	-0.96	0.13	0.11	Constant of Channel maintenance (C)	-0.91	-0.12	-0.34
Infiltration Number (If)	0.96	0.13	-.--	Infiltration Number (If)	-0.91	-0.13	-0.34
Form Factor (Rf)	0.92	-.--	0.36	Form Factor (Rf)	0.88	0.35	0.22
Elongation Ratio (Re)	0.87	-0.18	0.41	Elongation Ratio (Re)	0.87	-0.41	0.14
Texture ratio (T)	0.86	0.42	-0.29	Texture ratio (T)	0.87	0.38	0.29
Drainage Intensity (Id)	0.77	-0.56	0.21	Drainage Intensity (Id)	0.68	0.66	0.32
Compactness Constant (Cc)	-.--	-0.94	-.--	Compactness Constant (Cc)	-.--	0.98	-.--
Circulatory Ratio (Rc)	0.26	0.92	-0.23	Circulatory Ratio (Rc)	-.--	-0.92	0.20
Relief ratio (Rr)	0.48	0.62	0.39	Relief ratio (Rr)	0.47	0.58	-0.46
Mean Bifurcation Ratio (Rbm)	0.48	-0.55	-0.66	Mean Bifurcation Ratio (Rbm)	0.37	-0.23	0.89

Table 6: Priorities of sub-watersheds and their ranks

Sub-watershed	R_r	R_c	C_c	C	D_d	D_i	R_e	R_f	I_f	R_{bm}	L_o	F_s	T	Compound parameter C_p	Final priority
SW-I	4	3	4	3	4	1	6	5	3	4	3	3	4	3.62	4
SW-II	6	5	2	2	5	5	2	2	5	2	2	5	2	3.46	3
SW-III	5	1	6	5	2	2	3	3	2	1	5	2	3	3.08	1
SW-IV	2	2	5	4	3	3	4	4	4	5	4	4	5	3.77	5
SW-V	1	6	1	6	1	4	4	5	1	3	6	1	1	3.09	2
SW-VI	3	4	3	1	6	6	1	1	6	6	1	6	6	3.85	6

stronger positive loadings and moderate loadings on CC, RR, and ID. The higher circulation ratio suggests that watersheds are less compact and perhaps longer due to negative stress on the RC. The component 3 appears to be the branching structure of drainage. Higher positive loadings on the RBM show that watersheds with higher scores on this component have more complex bifurcation pattern, suggesting a mature drainage system. The negative loading on RR infers that these watersheds may have lower relief ratio, reflecting less elevation difference within watershed.

The prioritization of watersheds and their ranks is presented (Table 6). It reveals that SW-III ranked first with minimum compound values of 3.08, indicating the highest priority for management. SW-V is in second place with a composite value of 3.09. SW-II is in third place with a composite value of 3.46. This should be the next focus of management of watershed. SW-I is ranked fourth with a composite value of 3.62, indicating medium priority. SW-IV is ranked fifth with a composite value of 3.77. SW-VI ranked sixth with highest composite value of 3.85, indicating lowest priority for management among the six sub-watersheds. Higher ranked sub-watersheds show high erosion and surface runoff, and are considered as potentially suitable areas for construction of water conservation structures. Prioritization based on morphometric aspects helps to efficiently allocate resources and plan interventions. By addressing the most important watersheds first, management efforts can be more effective and sustainable in improving the overall health and functionality of watershed system.

Discussion

Morphometric analysis of river basin provides detailed information regarding the hydrological and geomorphological characteristics; each parameter is given a priority rank as per their influence on recharging the aquifer, and on that basis, watersheds are prioritized (Nanda *et al.,* 2021; Manjare *et al.,* 2020). The study suggests that SW-III has the highest priority due to its high drainage density, stream frequency, and infiltration number, which suggest high runoff and erosion risk. SW-V also exhibits steep slopes and erosion potential. SW-VI is given the lowest preference because it has low drainage density, high permeability, and low slope which reduces runoff and erosion. Soil in the basin has a loose texture, high capillarity, and strong percolation capacity, which allows efficient groundwater recharge. Water-holding capacity and groundwater infiltration rate are substantially affected due to presence of red gravel mixed with yellow and red soils (Li *et al.,* 2023). Groundwater movement significantly influenced by sandstone and shale formations of the Vindhyan Supergroup, particularly in fractured and well-jointed sandstone areas (Tiwari and Kushwaha 2018). Geological characteristics make the region susceptible to groundwater scarcity during summer. These findings suggest that SW-III and SW-V require urgent soil and water conservation measures, including afforestation, check dams and contour bunds to reduce runoff and erosion. Meanwhile, SW-VI, being more stable, may require less interventions. Afforestation and increasing vegetative cover help in stabilizing soil, reducing surface runoff, and enhancing water infiltration (Subbulakshmi and Nanda, 2024). Check dams and percolation ponds help slow runoff and help replenish groundwater in high-priority areas. Contour bunding and terracing are implemented on steep slopes, cutting down water flow and preventing soil degradation. Areas prone to sediment transport, gully plugging and silt traps can be beneficial for reducing erosion and minimizing sediment deposition in critical sub-watersheds. Integration of these measures collectively contributes to sustainable land and water management, ensuring soil conservation and enhanced groundwater availability.

Conclusions

Morphometric studies are an important prerequisite for all hydrological and quantitative geomorphological research. Morphometric analysis of Bichhiya Basin based on several drainage characteristics has been attempted, using GIS and remote sensing (RS) technologies. Three aspects were used to group all morphometric parameters (linear, areal, and relief aspects). The Bichhiya River has a length of around 55 km and is a 6th-order stream. The basin features a dendritic drainage pattern generally, with lower-order streams predominating. The extremely low value of drainage density (0.81) of the Bichhiya Basin indicates porous subsoil. The study reveals significance of prioritizing watersheds based on the analysis of morphometric parameters of the Bichhiya River Sub-basin, using remote sensing, GIS as well as PCA. These technologies are effective in visualizing hydrological information to prioritize watersheds, which is important for the planning as well as management of hydrological resources. The morphometric parameters of sub-watersheds within the Bichhiya River Basin reflect their unique relationship with the hydrological aspects of region. The sub-watershed prioritization is determined by PCA analysis and giving rank linear, relief as well as aerial aspect based on their susceptibility to erosion. Soil and geology of are also important aspects for watershed prioritization. play a key role in determining watershed prioritization in the Bichhiya River Sub-basin. The loose-textured soils of area support efficient groundwater recharge. The area with fractured and jointed sandstone also promotes for groundwater recharge. By soil and geological insights with morphometric analysis using GIS and PCA, it's possible to pinpoint sub-watersheds that need urgent soil conservation, supporting sustainable natural resource management. The result of the priority assessment show that sub-watersheds SW-III and SW-V are at risk of erosion. The study recommends to prioritise water harvesting, conservation, and erosion prevention in the Bichhiya River Basin for integrated watershed development. The management groundwater resources in the area can be enhanced by implementing artificial recharge structures such as boulder dams, check dams, contour trenches, and percolation ponds. Overall, prioritizing watersheds can guide to highlight sensitive areas that need immediate attention and conservation efforts. Based on results of study, policy makers can select watersheds and make new policies for soil and water conservation.

The water harvesting structures may be helpful to reduce runoff, prevent soil erosion, as well as recharge the aquifer in study area.

Authors' Contributions

RNT: Conception/Design and Interpretation of Data, Drafting of Original Draft of Manuscript and Revision. **PT:** Data Collection. **BS:** Drafting of Figures, Literature Review. **ASB:** Data Collection, Literature Review. **AKM:** Writing-Original Draft, Revision.

Conflict of interests

With regard to the publications, the authors have no conflicts of interest.

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