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ORIGINAL PAPER

# Prioritization of sub-watersheds of Teesta River according to soil erosion susceptibility using multi-criteria decision-making in Sikkim and West Bengal

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**Abstract**
Identification of the areas vulnerable to soil erosion through the prioritization of watersheds can help in the planning and execution of suitable conservational measures. In this study, prioritization for soil erosion of 14 sub-watersheds of the Teesta was determined through morphometric parameters using the analytical hierarchical process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). The relative weights of various parameters were determined using AHP. For the evaluation of soil erosion hazard, 10 factors are used: bifurcation ration ($R_b$), circulatory ratio ($R_c$), basin length ($L$), stream frequency ($F_s$), drainage density ($D_d$), basin perimeter ($P$), basin width ($W$), shape factor ($B_s$), drainage texture ($D_t$), and elongation ratio ($R_e$). The results demonstrate that sub-watersheds 1 and 4 have been ranked 1 and 2 in terms of highest closeness ($cl_i^+$) to an ideal solution with 0.774 and 0.434 respectively. These sub-watersheds must be given the highest priority for soil conservation measures, to ensure future sustainable agriculture.

**Keywords** Sub-watershed · Soil erosion · Prioritization · Analytical hierarchical process (AHP) · Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)

## Introduction

Watershed is important for the management of natural resources and natural hazards in long-term development (Khan et al. 2001; Aouragh and Essahlaoui 2018). Effective watershed management necessitates a thorough understanding of the hydrological behavior of the watershed (Gajbhiye et al. 2013). A detailed analysis of each watershed is required to establish a management plan. Morphometric analysis is a useful tool for assessing and understanding the behavior of hydrological systems (Bhattacharya et al. 2021). Hydrological and geomorphic processes that can be measured with morphometry include soil erosion, runoff, sedimentation, and drainage geometry (Arabameri et al. 2020). The watershed is the basic unit of morphometric analysis, which was developed by Miller (1953); Horton (1945); Schumm (1956); Strahler (1957); and Sameena et al. (2009).

Soil erosion risk mapping and soil conservation planning, which are normally done with the use of erosion models, are becoming increasingly important in a watershed for long-term agricultural and natural resource development (Singh 2009; Haokip et al. 2021; Novara et al. 2011). Prioritization of watersheds is a well-known scientific method for identifying places that are prone to soil erosion and flooding, as well as appropriate for groundwater exploration (Magesh and Chandrasekar 2012; Arabameri et al. 2018; Jothimani et al. 2020; Bhattacharya et al. 2021). The accelerated erosion can be reduced in a watershed by identifying and prioritizing soil erosion-prone areas (Prieto-Amparán et al. 2019; Nitheshnirmal et al. 2019).

There are numerous methods for prioritizing watersheds such as Universal Soil Loss Equation (USLE) and Sediment

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Yield Index (SYI), including the analytical hierarchy process (AHP) using morphometric analysis of the watershed (Anees et al. 2018; Arulbalaji et al. 2019). In situations, when the data is scarce, morphometric analysis can be quite useful (Javed et al. 2011; Pramanik 2016; Ameri et al. 2018). As the linear and shape parameters have a direct and indirect relationship with erodibility, morphometric analysis assists in the identification of sensitive zones that are susceptible to soil erosion (Farhan et al. 2017; Shivhare et al. 2018; Haokip et al. 2021). Furthermore, this factor is a useful tool for choosing sub-basins without having to examine the region's soil map (Pandey and Sharma 2017; Meshram et al. 2020). Assessing the soil erosion risk, particularly in mountainous areas, where it is difficult due to the variability of topography and the lack or insufficiency of essential data. The present study aims to identify the sensitive soil erosion-prone sub-watersheds in the upper catchment and lower undulating plain catchment of the Teesta basin based on morphometric characteristics using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS).

## Study area

The study area is the sub-watersheds of the Teesta River basin, which is situated in Sikkim and West Bengal (Fig. 1). It is important to discuss the basin as a whole in the Indian part. The Teesta exhibits large variability in geography, the glacial, periglacial deposition, dissected valley, flood plain, and landslide slope (Mukhopadhyay 1984; Rudra 2008, Sarkar 2008). The lower section of the basin has a gentle slope intended for flat topography. The southern part of the Teesta River Basin has a 4° slope. The central part has an increased 23° to 51° slope, the northern part has 25°, and the extreme northern part has a high slope (Mukhopadhyay 1984; Mandal and Chakrabarty 2016; Pal et al. 2016; Karmokar and De 2020).

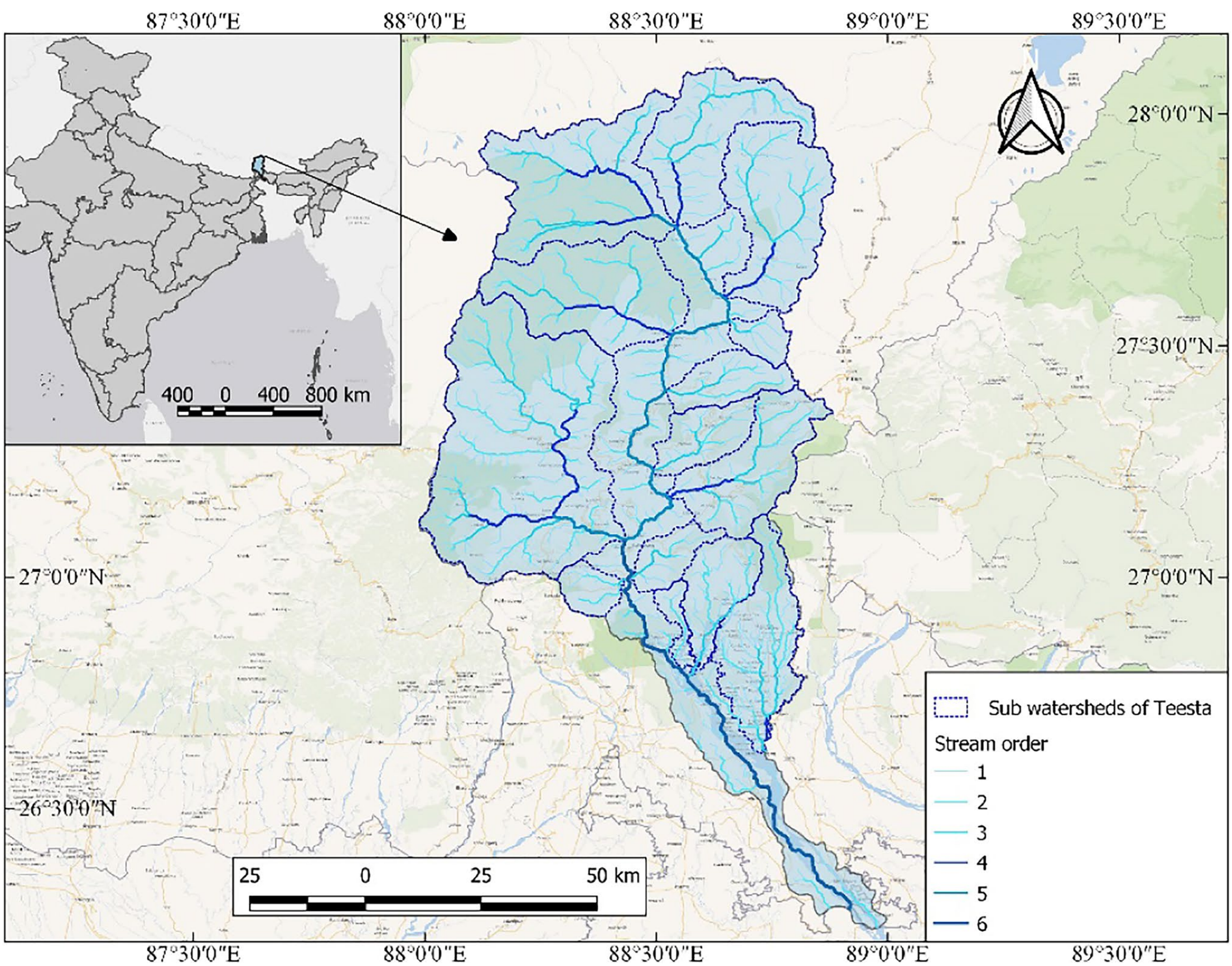


**Fig. 1** Location of the study area

## Methodology

The geospatial techniques were applied to delineate the soil erosion potential zones of the Teesta River basin using the morphometric parameter. The Aster DEM was used to define the drainage and watershed boundaries. Arc GIS tools were used to derive and calculate morphometric parameters of the watersheds. Morphometric parameters were calculated based on the mathematical equation illustrated in Table 1. The morphometric parameters were categorized into two categories. The parameter includes bifurcation ration ($R_b$), circulatory ration ($R_c$), basin length ($L$), stream frequency ($F_s$), drainage density ($D_d$), basin perimeter ($P$), basin width ($W$), shape factor ($B_s$), drainage texture ($D_t$), and elongation ratio ($R_e$). Category-1 comprises all parameters that have a direct relationship with soil erodibility, while category-2 has an inverse relationship. The higher the values of linear parameters the greater erosion will be and the lower values of shape parameters indicate higher susceptibility to erosion (Arabameri et al. 2019; Nitheshnirmal et al. 2019; Amiri et al. 2019). After determining and computing the effective values of the morphometric parameters, prioritization was done using the AHP and the TOPSIS MCDM models. A methodological chart are shown in Fig. 2.

### AHP model

The weights of criteria can be determined in a variety of ways, in this study, the weights of each criterion were assigned to Saaty's relative importance scale (Saaty 1990; Arulbalaji et al. 2019). A pairwise comparison matrix was used to compute the weights. Table is derived from a review of the literature and personal experience (Arabameri et al. 2020). First, using Saaty's rating scale (Table 2), pairwise comparison matrices are constructed for criteria based on relative influence on soil erodibility (Nitheshnirmal et al. 2019). The pairwise comparison matrix was created by taking into account the information provided by the relevant literature (Ranjan et al. 2013; Jaiswal et al. 2015; Gaikwad and Bhagat 2018; Meshram et al. 2019; Arulbalaji et al. 2019; Saha et al. 2021).

The consistency ratio (CR) is the method through, which the validity of relative influence is measured after the comparison matrix has been constructed (Saaty 1990; Arabameri et al. 2020). A CR value $< 0.1$ is acceptable. Equations (1) to (2) were used to calculate CR (Novara et al. 2011).

$$\mathrm{CR} = \frac{CI}{RI} \tag{1}$$

$$\mathrm{CI} = \frac{\lambda_{\max - n}}{n - 1} \tag{2}$$

$$\Lambda_{\max} = \frac{\sum \lambda}{n} \tag{3}$$

$$\lambda = \frac{wsv}{w} \tag{4}$$

$$\mathrm{wsv} = A \times W \tag{5}$$

where CR is the consistency ratio, CI is the consistency index, RI is a random index (Table 3), $n$ is the number of criteria, $\lambda_{\max}$ is the largest special matrix value, $\lambda$ is the

**Table 1** Formulas adopted for computation of morphometric parameter

| Morphometric parameters | Formula | References |
|---|---|---|
| Bifurcation ratio ($R_b$) | $R_b$ = Nu / Nu + 1 where Nu = number of stream segments present in the given order, Nu + 1 = number of segments of the next higher order | Schumm 1956 |
| Circulatory ratio ($R_c$) | $R_c = 4\pi A/P2$ where $A$, area of the basin; $P$, perimeter of the basin | Miller 1953 |
| Basin length ($L$) | Length of Basin in km | Horton 1945 |
| Basin width in km ($W$) | Width of the basin in km | Horton 1945 |
| Stream frequency ($F_s$) | $F_s$ = Nu/Au where Nu = number of streams, Au = area | Horton 1945 |
| Drainage density ($D_d$) | $D_d$ = Lu/Au, where Lu = length of the stream, Au = area | Horton 1945 |
| Basin perimeter in km ($P$) | Perimeter of the watershed in km | Horton 1945 |
| Basin width in km ($W$) | Width of the basin in km | Horton 1945 |
| Shape factor ($B_s$) | $B_s = P_u/P_c$ where $P_u$ = perimeter of the circle of watershed $P_c$ = perimeter of watershed | Sameena et al. 2009 |
| Drainage texture | $D_t$ = Nu/$P$ where, Nu = total no. of stream, $P$ = perimeter of watershed | Horton 1945 |
| Elongation ratio ($R_e$) | $R_e = D_c/L_b$ where $D_c$ = diameter of basin, $L_b$ = basin length | Schumm 1956 |

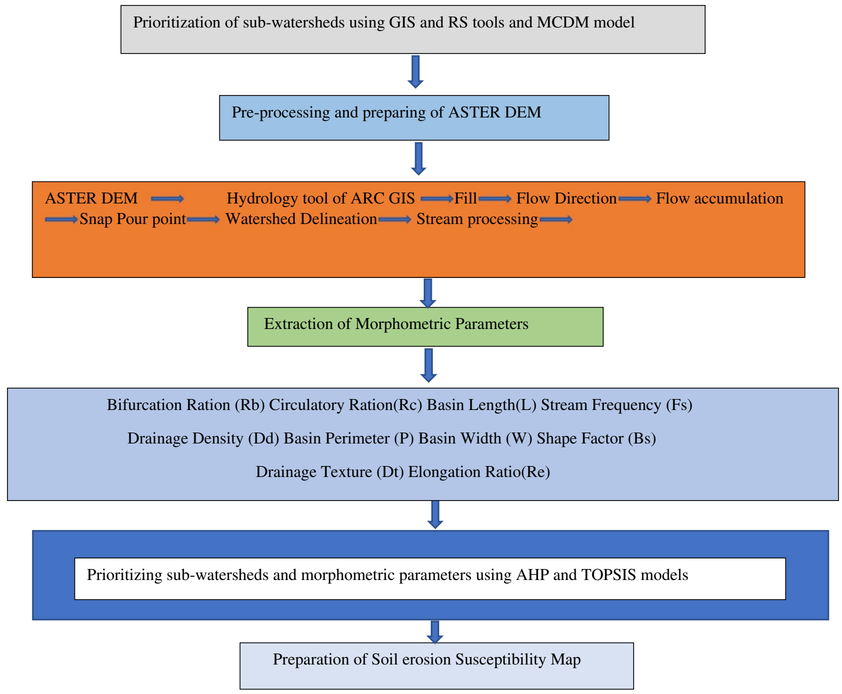


**Fig. 2** Methodology chart

consistency vector, WSV is the weighted sum vector, *A* is pairwise comparison matrix, and *W* is the weight of criteria vector.

## Technique for Order of Preference by Similarity to the Ideal Solution Model (TOPSIS)

The most well-known decision-making model, TOPSIS (Hwang and Yoon 1981), is one of the most technical schedules for prioritizing alternatives through the distance from the ideal and anti-ideal points. It is simple to find the best answer. A positive ideal indicator positive ideal solution (PIS) will provide the best value, while a negative ideal indicator negative ideal solution (NIS) will provide the poorest value, and a ranking will be determined accordingly (Behzadian et al. 2012; Chen 2000). The outcome of these two distances is expressed as a closeness coefficient, which is based on the fact that the option with a numerical value of a larger coefficient of attraction is known as the preferred option (Ustaoglu et al. 2021).

The TOPSIS procedure is as follows (Aouragh and Essahlaoui 2018).

Step 1: In the matrix alternatives were used in rows and evaluation criteria were used in columns (Sadhasivam et al. 2020). In the study, the decision matrix D was created using 15 alternative sub-watersheds and 10 criteria (Fig. 3).

$$D = \begin{array}{c|cccc} & C_1 & C_2 & - & C_n \\ \hline A_1 & X_{11} & X_{12} & - & X_{1n} \\ A_2 & X_{21} & X_{22} & & X_{2n} \\ - & - & - & - & - \\ A_m & X_{n1} & X_{n2} & & X_{n3} \end{array} \quad (6)$$

where $A_1$, $A_2 \ldots$, $A_m$ are possible alternatives among, which decision-makers have to choose.

$C_1$, $C_2 \ldots$, $C_n$ are criteria with which alternative performance is measured; Xij is the rating of alternative Ai concerning criterion Cj.

Step 2: The criteria are stated in various units, and the decision matrix should be normalized.

**Table 2** The comparison scale for the relative pairwise comparison matrix (Saaty 1977)

| Value | Relative importance |
|---|---|
| 1 | Equal |
| 3 | Moderately |
| 5 | Strongly |
| 7 | Very strongly |
| 9 | Extremely |
| 2, 4, 6, and 8 | Intermediate between 2 adjacent judgements |

**Table 3** Values of random index (RI)

| $N$ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RI | 0.00 | 0.00 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 | 1.51 | 1.53 |

$$n_{ij} = \frac{Xij}{\sqrt{\sum_{i=1}^{m} Xij^2}} \quad (7)$$

where $n_{ij}$ is a normalized decision matrix element and $Xij$ is the i-th alternative performance in j-th criteria.

Step 3: Calculate the weighted normalized decision matrix as follows

$$v_{ij} = n_{ij} \text{ X } w_j, i = 1, ..., m; j = 1, ..., n. \quad (8)$$

where $v_{ij}$ is the weighted normalized matrix element, $n_{ij}$ is the normalized matrix element, $w_j$ is the weight of criteria $_j$. The weights of the criteria were calculated using Saaty's analytical hierarchy process. To compute weight, we employed the AHP method, which is widely used in the literature (Arulbalaji et al. 2019; Saha et al. 2021).

Step 4: Identification of the positive ideal solution and negative ideal solution as given in reference (Strahler 1957) calculation of the positive-ideal ($A^+$) and negative ideal ($A.^-$) solutions respectively (Aouragh and Essahlaoui 2018)

$$A^+ = \{((maxv_{ij}/j \in J), (minv_{ij}/j \in J'))/i = 1,2, \ldots, m\} = v_1^+, v_2^+, \ldots, v_m^+ \quad (9)$$

$$A^- = \{((maxv_{ij}/j \in J), (minv_{ij}/j \in J'))/i = 1,2, \ldots, m\} = v_1^-, v_2^-, \ldots, v_m^- \quad (10)$$

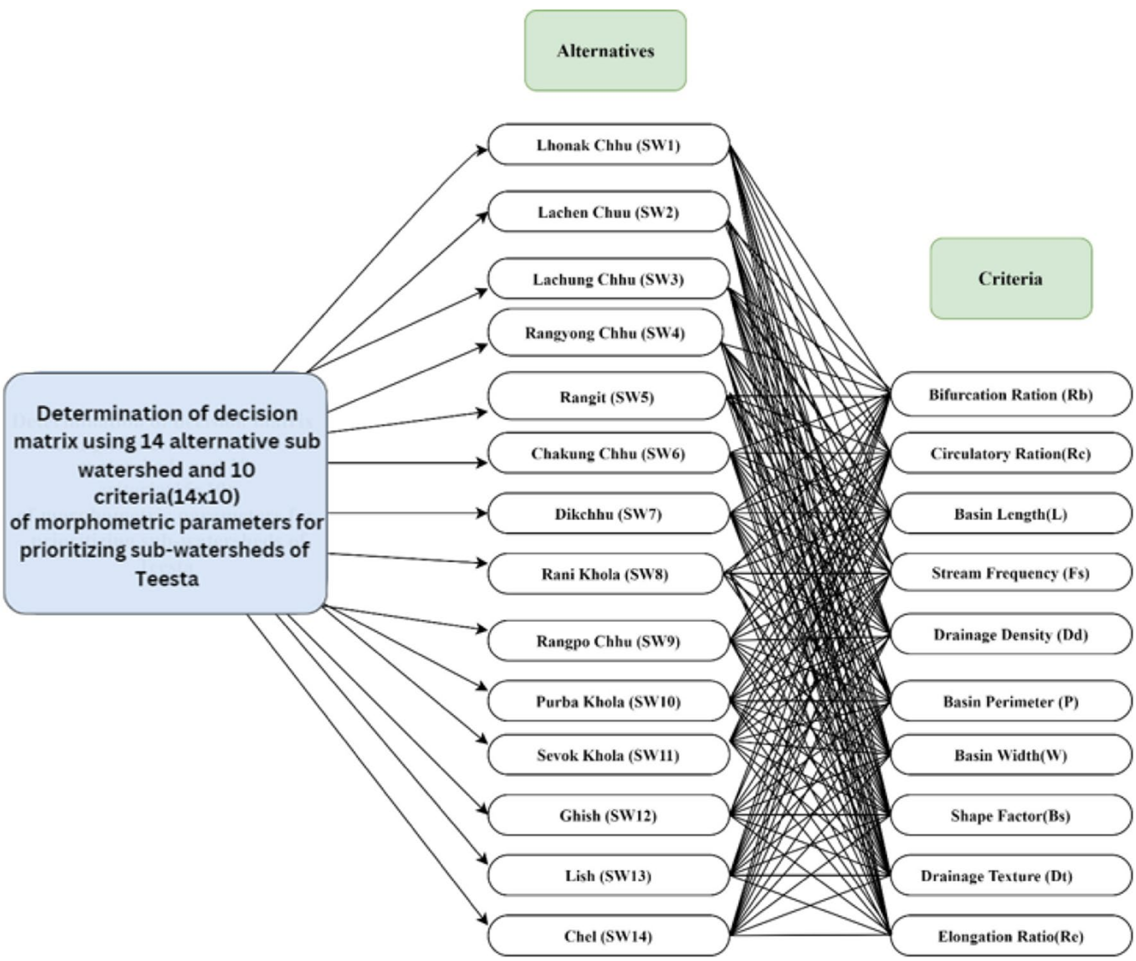


**Fig. 3** Decision tree

**Table 4** Selected criteria along with its type and weights (AHP)

| Criteria | $R_b$ | $D_d$ | $D_t$ | $F_s$ | $R_c$ | $P$ | $R_e$ | $B_s$ | $L$ | $W$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Criteria type | Positive | Positive | Positive | Positive | Negative | Positive | Negative | Negative | Positive | Positive |
| Criteria weights | 0.200 | 0.178 | 0.156 | 0.111 | 0.089 | 0.089 | 0.067 | 0.044 | 0.044 | 0.022 |

where $J$ is associated with the positive criteria, and $J'$ is associated with the negative criteria.

Step 5: Calculation of distances to positive ideal ($S^+$) and negative ideal ($S^-$) points by Eq. 11 and Eq. 12.

$$S_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_{ij}^+\right)^2} \tag{11}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_{ij}^-\right)^2} \tag{12}$$

Step 6: Final step is to calculate the relative closeness (Eq. 13) to the ideal solution.

$$cl_i^+ = \frac{S_i^-}{S_i^+ + S_i^-};0 \le 1;\; i = 1, 2 \ldots \ldots, \tag{13}$$

where $cl_i^+$ is closeness coefficient, $S_i^+$ is the positive ideal solution (PIS), and $S_i^-$ is the negative ideal solution (NIS). If $cl_i^+$=0 the decision point is near the absolute negative ideal solution. If, $cl_i^+$=1, the decision point/alternative is near the absolute positive ideal solution (Ustaoglu et al. 2021). In the final step of TOPSIS, alternatives (sub-watershed of the study area) were ranked according to calculated $cl_i^+$ values.

## Result and discussion

The first stage in proper planning and management of natural resources, as well as the determination of soil and water conservation measures, is the identification and prioritization of sub-watersheds within a watershed. The Teesta River sub-watersheds have been segmented into 14 sub-watersheds for prioritizing purposes, namely; SW-1 to SW-14. The ranking of distinct sub-watersheds according to the order in which they must be taken for soil conservation measures is known as watershed prioritization (Nitheshnirmal et al. 2019). Morphometric analysis is an important tool for the prioritization of sub-watersheds (Meshram et al. 2020). The present study is used 10 erosion risk assessment morphometric parameters, i.e., bifurcation ratio ($R_b$), shape factor ($B_s$), drainage density ($D_d$), stream frequency ($F_s$), drainage texture ($D_t$), form factor ($R_f$), circularity ratio ($R_c$), and elongation ratio ($R_e$), basin perimeter ($P$), shape factor ($B_s$), basin width ($W$), and basin length ($L$) for prioritizing sub-watersheds for treatment and conservation measure. Erodibility is directly related to linear parameters such as drainage density, stream frequency, bifurcation ratio, and drainage texture; the higher the value, the greater the erodibility. Erodibility is inversely proportional to shape parameters such as circularity ratio, basin shape, and compactness coefficient; the lower the value, the greater the erodibility (Arabameri et al. 2018; Aouragh and Essahlaoui 2018). The parameters $R_b$, $D_d$, $D_t$, $F_s$, $P$, $L$, and $W$ were used as positive criteria in the study area, with maximum values indicating high erosion, and $R_c$, $R_e$, and $B_s$ were used as negative criteria, with minimum values indicating high erosion. In the study, the relative weights of each criterion were determined through AHP (Table 4), using Microsoft Excel, and the weights were used as input for TOPSIS to select the best alternatives.

Based on TOPSIS greatest closeness ($cl_i^+$) to ideal solution (Table 5), sub-watersheds were classified as very high (0.435–0.774), high (0.360–0.434), medium (0.307–0.359), less (0.229–0.306), and very less (0.199–0.228). Sub-watersheds (SW5, SW1, SW3, SW4, SW14) have been discovered in Fig. 4 to be particularly vulnerable to soil erosion, and conservation measures can be implemented in these micro watersheds as a priority to preserve the long-term sustainability of agriculture by preventing excessive soil loss through erosion.

## Conclusion

Prioritization of sub-watersheds is the order in which sub-watersheds in a basin are ranked for soil conservation measures. The morphometric parameters play an important role in hydrological behavior, which identifies the locations that are sensitive to natural hazards such as soil erosion of a river basin. Without huge expenses and time, it is possible to claim that sub-watersheds may be prioritized based on morphometric criteria to execute conservation measures. The study demonstrated that the digital elevation model (DEM) with GIS is an effective tool for sub-watershed delineation and extraction of its morphometric factors, and the results of the TOPSIS technique in relation to erosion may strongly suggest that the necessary protection measures should be taken to minimize soil erosion. In order to ensure the sustainable growth of agricultural and natural resources, sub-watershed with very high (SW 5) and high (SW 1, SW

**Table 5** Values of morphometric parameters and closest coefficient to the ideal solution with ranking(R) and priority index of Teesta sub-watersheds

| Sub-watersheds | $R_b$ | $D_d$ | $D_t$ | $F_s$ | $R_c$ | $P$ | $R_e$ | $B_s$ | $L$ | $W$ | $cl_i^+$ | $R$ | Priority index |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lhonak Chhu (SW1) | 1.72 | 1.14 | 6.62 | 1.3 | 0.33 | 193.46 | 0.72 | 0.58 | 49.33 | 29.05 | 0.426 | 3 | Medium |
| Lachen Chuu (SW2) | 1.9 | 1.07 | 5.4 | 1.3 | 0.31 | 166.07 | 0.94 | 0.37 | 31.55 | 15.64 | 0.359 | 6 | High |
| Lachung Chhu (SW3) | 1.63 | 1.06 | 6.67 | 1.32 | 0.41 | 152.66 | 0.46 | 0.48 | 43.3 | 24.49 | 0.402 | 5 | Medium |
| Rangyong Chhu (SW4) | 1.79 | 1.07 | 7.19 | 1.32 | 0.46 | 149.92 | 0.36 | 0.18 | 42.6 | 21.05 | 0.434 | 2 | High |
| Rangit (SW5) | 1.51 | 2.46 | 12.97 | 1.46 | 0.47 | 239.48 | 0.77 | 0.6 | 54.68 | 31.68 | 0.774 | 1 | Very high |
| Chakung Chhu (SW6) | 2.03 | 0.91 | 2.99 | 0.96 | 0.34 | 49.09 | 0.29 | 0.43 | 13.8 | 9.78 | 0.273 | 12 | Less |
| Dikchhu (SW7) | 2.01 | 0.91 | 3.91 | 1.3 | 0.46 | 81.78 | 0.41 | 0.48 | 26.79 | 11.25 | 0.276 | 11 | Less |
| Rani Khola (SW8) | 1.4 | 0.89 | 5.12 | 1.57 | 0.53 | 78 | 0.46 | 0.56 | 28.46 | 13.48 | 0.281 | 10 | Less |
| Rangpo Chhu (SW9) | 1.72 | 0.94 | 5.26 | 1.26 | 0.38 | 137 | 0.33 | 0.34 | 37.81 | 14.67 | 0.3478 | 7 | Medium |
| Purba Khola (SW10) | 1.67 | 0.95 | 3.22 | 1.28 | 0.46 | 67.96 | 0.42 | 0.42 | 19.06 | 10.41 | 0.228 | 13 | Very Less |
| Sevok Khola (SW11) | 1.65 | 0.99 | 3.87 | 1.42 | 0.71 | 47.85 | 0.62 | 0.63 | 13.9 | 13.29 | 0.199 | 14 | Very Less |
| Ghish (SW12) | 1.7 | 1.08 | 3.49 | 1.24 | 0.31 | 112.75 | 0.4 | 0.4 | 32.8 | 14.75 | 0.296 | 9 | Less |
| Lish (SW13) | 1.77 | 1.16 | 1.35 | 1.26 | 0.17 | 78.79 | 0.19 | 0.18 | 21.93 | 3.2 | 0.306 | 8 | Less |
| Chel (SW14) | 1.91 | 1.27 | 4.03 | 1.3 | 0.21 | 188.73 | 0.25 | 0.3 | 56.78 | 17.53 | 0.411 | 4 | High |

$R_b$, bifurcation ration; $R_c$, circulatory ratio; $L$, basin length; $F_s$, stream frequency; $D_d$, drainage density; $P$, basin perimeter; $W$, basin width; $B_s$, shape factor; $D_t$, drainage texture; $R_e$, elongation ratio; these values were calculated by ArcGIS 10.7 and these data also used in paper (Sarkar et al. 2022)

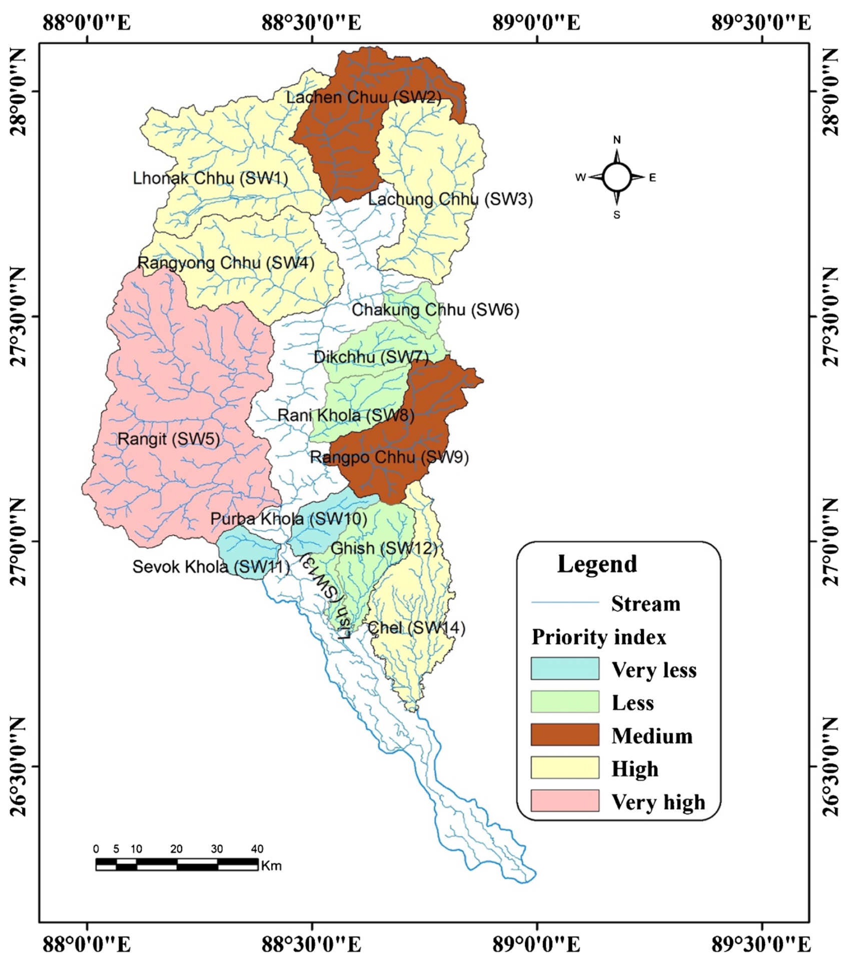


**Fig. 4** Soil erosion prioritization using TOPSIS model in Teesta sub-watersheds

3, SW 4, SW 14) susceptibility to erosion should be taken care of for soil and water conservation measures. Our study also examines how decision-makers might use MCDM approaches (AHP and TOPSIS) with Microsoft Excel in the fields of soil and water resources. Lastly, where soil erosion is high and slope is steep, mechanical methods such as contour bunds may be advised for installation in very high and high priority sub-watersheds.

**Author contribution** All authors have contributed equally.

**Data Availability** Data that support the finding of this study are available from the corresponding author.

## Declarations

**Conflict of interest** The authors declare no competing interests.

## References


Ameri AA, Pourghasemi HR, Cerda A (2018) Erodibility prioritization of sub-watersheds using morphometric parameters analysis and its mapping: a comparison among TOPSIS, VIKOR, SAW, and CF multi-criteria decision-making models. Sci Total Environ 613–614:1385–1400. https://doi.org/10.1007/s12594-022-1995-0

Amiri M, Pourghasemi HR, Arabameri A, Vazirzadeh A, Yousefi H, Kafaei S (2019) Prioritization of flood inundation of Maharloo Watershed in iran using morphometric parameters analysis and TOPSIS MCDM model. In Spatial modeling in GIS and R for earth and environmental sciences (pp. 371–390). Elsevier. https://doi.org/10.1007/s12594-022-1995-0

Anees MT, Abdullah K, Nawawi MN, Norulaini NA, Syakir MI, Omar AK (2018) Soil erosion analysis by RUSLE and sediment yield models using remote sensing and GIS in Kelantan state Peninsular Malaysia. Soil Res 56(4):356. https://doi.org/10.1071/SR17193

Aouragh MH, Essahlaoui A (2018) A TOPSIS approach-based morphometric analysis for sub-watersheds prioritization of high Oum Er-Rbia basin Morocco. Spat Inform Res 26(2):187–202. https://doi.org/10.1007/s41324-018-0169-z

Arabameri A, Pradhan B, Pourghasemi HR, Rezaei K (2018) Identification of erosion-prone areas using different multi-criteria decision-making techniques and GIS. Geomat Nat Haz Risk 9(1):1129–1155. https://doi.org/10.1080/19475705.2018.1513084

Arabameri A, Pradhan B, Rezaei K, Conoscenti C (2019) Gully erosion susceptibility mapping using GIS-based multi-criteria decision analysis techniques. CATENA 180:282–297. https://doi.org/10.1016/j.catena.2019.04.032

Arabameri A, Tiefenbacher JP, Blaschke T, Pradhan B, Bui DT (2020) Morphometric analysis for soil erosion susceptibility mapping using novel GIS-based ensemble model. Remote Sens 12(5):874. https://doi.org/10.3390/rs12050874

Arulbalaji P, Padmalal D, Sreelash K (2019) GIS and AHP techniques based delineation of groundwater potential zones: a case study from southern Western Ghats, India. Sci Rep 9(1). https://doi.org/10.1038/s41598-019-38567-x

Bhattacharya RK, Chatterjee ND, Acharya P, Das K (2021) Morphometric analysis to characterize the soil erosion susceptibility in the western part of lower Gangetic River basin, India. Arab J Geosci 14(6). https://doi.org/10.1007/s12517-021-06819-8

Behzadian M, Otaghsara SK, Yazdani M, Ignatius J (2012) A state-of the-art survey of TOPSIS applications. Expert Syst Appl 39(17):13051–13069. https://doi.org/10.1016/j.eswa.2012.05.056

Chen CT (2000) Extensions of the TOPSIS for group decision making under fuzzy environment. Fuzzy Sets Syst 114(1):1–9

Farhan Y, Anbar A, Al-Shaikh N, Mousa R (2017) Prioritization of semi-arid agricultural watershed using morphometric and principal component analysis, remote sensing, and GIS techniques, the Zerqa River Watershed Northern Jordan. Agric Sci 08(01):113–148. https://doi.org/10.4236/as.2017.81009

Gaikwad R, Bhagat V (2018) Multi-criteria prioritization for sub-watersheds in Medium River Basin using AHP and influence approaches. Hydrospatial Anal, 2(1):61–82. https://doi.org/10.21523/gcj3.18020105

Gajbhiye S, Mishra SK, Pandey A (2013) Prioritizing erosion-prone area through morphometric analysis: an RS and GIS Perspective. Appl Water Sci 4(1):51–61. https://doi.org/10.1007/s13201-013-0129-7

Haokip P, Khan MA, Choudhari P, Kulimushi LC, Qaraev I (2021) Identification of erosion-prone areas using morphometric parameters, land use land cover and multi-criteria decision-making method: geo-informatics approach. Environ Dev Sustain. https://doi.org/10.1007/s10668-021-01452-7

Horton R (1945) Erosional development of streams and their drainage basins: hydrological approach to quantitative morphology. Geol Soc Am Bull 56:275–370. https://doi.org/10.1130/0016-7606(1945)56[275:EDOSAT]2.0.CO;2

Hwang CL, Yoon K (1981) Multiple attribute decision making methods and applications. Springer, Heidelberg. https://doi.org/10.1007/978-3-642-48318-9

Jaiswal R, Ghosh N, Galkate R, Thomas T (2015) Multi criteria decision analysis (MCDA) for watershed prioritization. Aquatic Procedia 4:1553–1560. https://doi.org/10.1016/j.aqpro.2015.02.201

Javed A, Khanday MY, Rais S (2011) Watershed prioritization using morphometric and land use/land cover parameters: a remote sensing and GIS based approach. J Geol Soc India 78(1):63–75. https://doi.org/10.1007/s12594-011-0068-6

Jothimani M, Dawit Z, Mulualem W (2020) Flood susceptibility modeling of Megech River Catchment, Lake Tana Basin, North Western Ethiopia, using morphometric analysis. Earth Syst Environ 5(2):353–364. https://doi.org/10.1007/s41748-020-00173-7

Karmokar S, De M (2020) Flash flood risk assessment for drainage basins in the Himalayan foreland of Jalpaiguri and Darjeeling Districts, West Bengal. Model Earth Syst Environ 6(4):2263–2289. https://doi.org/10.1007/s40808-020-00807-9

Khan M, Gupta V, Moharana P (2001) Watershed prioritization using remote sensing and geographical information system: a case study from Guhiya India. J Arid Environ 49(3):465–475. https://doi.org/10.1006/JARE.2001.0797

Magesh NS, Chandrasekar N (2012) GIS model-based morphometric evaluation of Tamiraparani subbasin, Tirunelveli district, Tamil Nadu India. Arab J Geosci 7(1):131–141. https://doi.org/10.1007/s12517-012-0742-z

Mandal SP, Chakrabarty A (2016) Flash flood risk assessment for upper Teesta river basin: using the hydrological modeling system (HEC-HMS) software. Model Earth Syst Environ 2(2). https://doi.org/10.1007/s40808-016-0110-1

Meshram SG, Alvandi E, Meshram C, Kahya E, Al-Quraishi AM (2020) Application of SAW and TOPSIS in prioritizing watersheds. Water Resour Manage 34(2):715–732. https://doi.org/10.1007/s11269-019-02470-x

Meshram SG, Alvandi E, Singh VP, Meshram C (2019) Comparison of AHP and fuzzy AHP models for prioritization of watersheds. Soft Comput 23(24):13615–13625. https://doi.org/10.1007/s00500-019-03900-z

Miller VC (1953) A Quantitative geomorphic study of drainage basin characteristics in the Clinch Mountain area, Virginia and Tennessee, Proj. NR 389–402, Tech Rep 3, Columbia University, Department of Geology, ONR, New York

Mukhopadhyay SC (1984) The Tista basin: a study in fluvial geomorphology. KP Bagchi and company, Calcutta

Nitheshnirmal S, Bhardwaj A, Dineshkumar C, Rahaman SA (2019) Prioritization of erosion prone micro-watersheds using morphometric analysis coupled with multi-criteria decision making. Proceedings 24(1):11. https://doi.org/10.3390/IECG2019-06207

Novara A, Gristina L, Saladino S, Santoro A, Cerdà A (2011) Soil erosion assessment on tillage and alternative soil managements in a Sicilian vineyard. Soil Tillage Res 117:140–147. https://doi.org/10.1016/j.still.2011.09.007

Pandey M, Sharma PK (2017) Remote sensing and GIS based watershed prioritization. 2017 IEEE International Geoscience and Remote Sensing Symposium (IGARSS). https://doi.org/10.1109/IGARSS.2017.8128420

Pal R, Biswas SS, Mondal B, Pramanik MK (2016) Landslides and floods in the Tista Basin (Darjeeling and Jalpaiguri Districts): historical evidence, causes and consequences. J Ind Geophys Union 20(2):66–72

Pramanik MK (2016) Morphometric characteristics and water resource management of Tista river basin using remote sensing and GIS techniques. J Hydrogeol Hydrol Eng, 05(01). https://doi.org/10.4172/2325-9647.1000131

Prieto-Amparán, Pinedo-Alvarez, Vázquez-Quintero, Valles-Aragón, Rascón-Ramos, Martinez-Salvador, Villarreal-Guerrero (2019) A multivariate geomorphometric approach to prioritize erosion-prone watersheds. Sustainability 11(18):5140. https://doi.org/10.3390/su11185140

Ranjan R, Jhariya G, Jaiswal RK (2013) Saaty's Analytical Hierarchical Process based prioritization of sub-watersheds of Bina River Basin using Remote Sensing and GIS. Am Sci Res J Eng Technol Sci (ASRJETS) 3(1):36–55. https://www.asrjetsjournal.org/index.php/American_Scientific_Journal/article/view/526

Rudra K (2008) Banglar Nadi Kotha. Sahitya Sansad

Saaty TL (1977) A scaling method for priorities in hierarchical structures. J Math Psychol 15(3):234–281. https://doi.org/10.1016/0022-2496(77)90033-5

Saaty TL (1990) Decision making for leaders: the analytic hierarchy process for decisions in a complex world. RWS publications.

Sadhasivam N, Bhardwaj A, Pourghasemi HR, Kamaraj NP (2020) Morphometric attributes-based soil erosion susceptibility mapping in Dnyanganga watershed of India using individual and ensemble models. Environ Earth Sci, 79(14). https://doi.org/10.1007/s12665-020-09102-3

Saha D, Talukdar D, Senapati U, Das TK (2021) Exploring vulnerability of groundwater using AHP and GIS techniques: a study in Cooch Behar District, West Bengal, India. Groundwater and Society: Applications of Geospatial Technology, 445-472

Sameena M, Krishnamurthy J, Jayaraman V, Ranganna G (2009) Evaluation of drainage networks developed in hard rock terrain. Geocarto Int 24(5):397–420. https://doi.org/10.1080/10106040802601029

Sarkar P, Mondal M, Roy K, Sarma US, Gayen SK (2022) Morphometric analysis to prioritize for flood risk of sub-watersheds of Teesta (Sikkim and West Bengal) through hazard degree (HD) and principal component analysis with weighted sum approach (PCAWSA). In: Islam, A., Das, P., Ghosh, S., Mukhopadhyay, A., Das Gupta, A., Kumar Singh, A. (eds) Fluvial Systems in the Anthropocene. Springer, Cham. https://doi.org/10.1007/978-3-031-11181-5_13

Sarkar S (2008) Flood hazard in the sub-Himalayan North Bengal, India. Environmental changes and geomorphic hazard, Book well New Delhi, Shillong, 247–262

Schumm SA (1956) Evaluation of drainage system and slopes in Badlands at Perth Amboy, New Jersey. Geol Soc Am Bull 67:597–646. https://doi.org/10.1130/0016-7606(1956)67[597:EODSAS]2.0.CO;2

Singh A (2009) Characterizing runoff generation mechanism for modelling runoff and soil erosion in small watershed of Himalayan region. ITC. https://www.iirs.gov.in/iirs/sites/default/files/StudentThesis/amarinder.pdf

Strahler AN (1957) Quantitative analysis of watershed geomorphology. Trans Am Geophys Union 38(6):913. https://doi.org/10.1029/TR038i006p00913

Shivhare N, Rahul AK, Omar PJ, Chauhan MS, Gaur S, Dikshit PK, Dwivedi SB (2018) Identification of critical soil erosion prone areas and prioritization of micro-watersheds using geoinformatics techniques. Ecol Eng 121:26–34. https://doi.org/10.1016/j.ecoleng.2017.09.004

Ustaoglu E, Sisman S, Aydınoglu A (2021) Determining agricultural suitable land in peri-urban geography using GIS and Multi Criteria Decision Analysis (MCDA) techniques. Ecological Modelling, 455, 109610. https://doi.org/10.1016/J.ECOLMODEL.2021.109610