Water Resources Management
https://doi.org/10.1007/s11269-020-02681-7

The Feasibility of Multi-Criteria Decision Making Approach for Prioritization of Sensitive Area at Risk of Water Erosion

Sarita Gajbhiye Meshram[1,2] · **Vijay P. Singh**[3,4] · **Ercan Kahya**[5] · **Ehsan Alvandi**[6] · **Chandrashekhar Meshram**[7] · **Shailesh Kumar Sharma**[8]

Received: 1 April 2020 / Accepted: 21 September 2020/Published online: 08 October 2020

Abstract

Morphometric analysis is not only important for a hydrological analysis, but also necessary in the management and development of a basin. In this study, we attempted to prioritize twenty sub-watersheds of Bamhani watershed considering the linear, aerial and relief aspects of the watershed that will be further used in the multi-criterion decision making (MCDM) analysis. ELECTRE, Vlsekriterijumskaoptimizacija I kompromisno resenje (VIKOR), and aggregate method. Remote sensing and GIS approach were employed in the morphometric analysis. Percentage of changes and intensity of change indices were used in the MCDM model validation. Based on the range of Borda/Copland model values, the sub-watershed 11 took place at the first rank, while the Compound Factor (CF) model placed in the second rank, implying to be the most susceptible sub-watersheds for erosion. Vulnerability of sub-watersheds to soil loss (erosion), the VIKOR models showed four vulnerability classifications as very high, high, moderate and low. In conclusion, our results of the morphometric studies appeared to be effective in estimating the erosion status and prioritization of the watershed concerned for the purpose of easy and early development and management of natural resources. A high reductive accuracy was observed by VIKOR in comparison to CF and ELECTRE models.

Keywords Watershed · Prioritization · Morphometric parameters · Soil erosion · Geographic information system · Multi-criteria decision making (MCDM)

1 Introduction

For sustainable development of natural resources to reduce impact of natural calamities, watershed is taken as developmental unit (UNEP 1997). Watershed management planning is

✉ Sarita Gajbhiye Meshram
saritagmeshram@tdtu.edu.vn

Extended author information available on the last page of the article

often undertaken for controlling losses from erosion in a watershed (Gajbhiye et al. 2015a, b; Meshram et al. 2018a, b, 2019) besides the tasks of evaluating the natural hazards and risk (soil erosion, floods, landslide, etc.) in sub-watersheds (Ministry of Agriculture 1985). Although several factors are involved in soil erosion, a major agent is the water in the problem of land deterioration in most parts of the world. Soil erosion is not a newly discovered problem, but it becomes a common country wide in general, and particularly is becoming visible in the watershed of the Narmada river basin.

Geomorphology, soil, slopes, uplands and lowlands have linkages and interrelationships among themselves and all are well recognized in the watershed management. Geomorphometric analysis initiated in the 1940s in hydrological analysis of the basins (Ministry of Agriculture 1985). Measurement and analysis of earth surface size and its shape are the subjects of the morphometry (UNEP 1997). Soil erosion, runoff, changing river courses, obliteration of river, stream, river sedimentation and drainage line characteristics are, in fact, hydrologic and geomorphic processes and ultimately related with morphometry (UNEP 1997). Therefore, it can be said that the morphometry of a basin explains its hydrological behaviours (Gajbhiye and Sharma 2017).

Nowadays, in morphometric analysis, the new technologies such as remote sensing (RS) and geographic information systems (GIS) are being used very effectively as old methods of calculating morphometry parameters were very time consuming and prone to error. It has already been proved that Digital Elevation Model (DEM) has a potential in the suggested analysis of hydrological data and water quality models (Mahmood et al. 2012; Gioti et al. 2013**)**. Durbude et al. (2001) prioritized watersheds on the basis of percentage of cultivated area, drainage density, and percent slope. In the present era, a majority of researchers have used RS and GIS for natural calamity assessments, prioritization of watershed and determination of various morphometric parameters in a drainage basin (Gajbhiye et al. 2014; Khadse et al. 2015; Amani and Safaviyan 2015; Meshram and Sharma 2017). This tool provides an easy environment for the manipulation and analysis of spatial data. Nowadays, multi-criteria decision making (MCDM) techniques have come up with various solutions of the problems in complex decision making (Mulliner et al. 2016; Salehi and Izadikhah 2014; Yu et al. 2017; Shojaie et al. 2017; Liu et al. 2006; Kobryń and Prystrom 2015; Shih et al. 2007; Raju et al. 2017; Chang and Lin 2014; Chang and Hsu 2009; Mira et al. 2016; Malekian and Azarniv 2016; Meshram et al. 2019, 2020; Dahmardeh Ghaleno et al. 2020).

In this study, under the lights of all the aforementioned previous studies, we aim to prioritize the sub-watersheds of the Bamhani watershed using a comprehensive methodological approach in order to provide some insights and help to develop some intuitions in the development and management plan. Moreover, the prioritization of the watershed has been easy procedures for fluvial geomorphology of individual basin and sub-basin, and thereby efficient control of soil erosion using different soil conservation measures could be possible for local authorities.

2 Materials and Methods

2.1 Study Area

In analyzing different morphometric parameters as well as identification of erosion prone areas using MCDM, we have chosen the Bamhani watershed following Meshram et al. (2017)

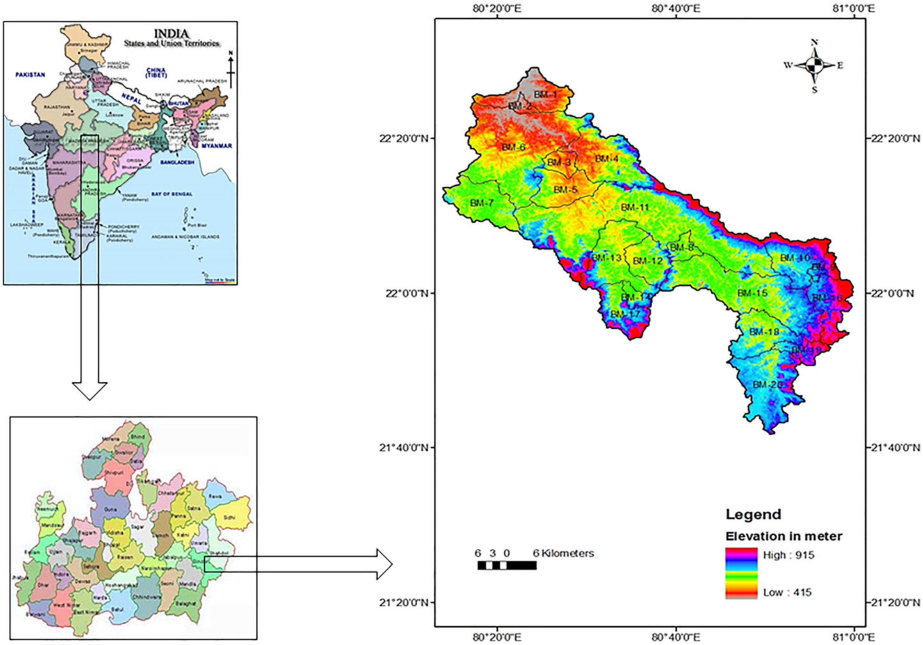

Fig. 1 Location map of the study area

(Fig. 1). The Bamhani watershed is geographically located in Mandla district between 21^{0}65′ 55"N, 22^{0}29′00"N latitudes and 80^{0}22′00″E, 81^{0}00′00″E longitudes. The watershed covers 2.542 km^{2} areas and located in the Madhya Pradesh's southern part. A warm summer and overall dryness, except during the south-western monsoon season characterizes the climate of Mandla district. Climate can be categorized as sub-tropical sub-humid with an annual median precipitation of 1178 mm. Roughly 90% of annual monsoon rainfall totals are observed during the period of June–October. The region includes both plain and undulated soils surrounded by grass, timber and farmland. Nearly 58% of the watershed is covered by forest as the residual areas are covered by degraded fields and water bodies, and agricultural plants cultivate in 19% of the region (Meshram et al. 2017).

2.2 Erodibility and Mapping

In the morphometric analysis and prioritization of Bamhani watershed, drainage networks are needed. DEM generated by Shutter Radar Topography Mission (SRTM) data was used to delineate a drainage and sub-watershed map (Fig. 2). The SRTM data resolution was 90 m*90 m (NASA). In addition, the parameters of streams (i.e., numbers and lengths) and watershed (i.e., area, perimeter, width and length) estimated by the GIS package ArcGIS. The parameters determined in the GIS environment were utilized to calculate linear parameters (i.e., drainage density, stream frequency) and shape parameters (i.e., elongation ratio, form factor, circulatory ratio) using pertinent formulae in Table 1.

Table 1: Computed Morphometric Parameters using respective formulae.

In the Bamhani watershed prioritization, MCDM techniques were used and shown in a flow-chart fashion (Fig. 3). In the first stage, we calculated morphometric parameters at each

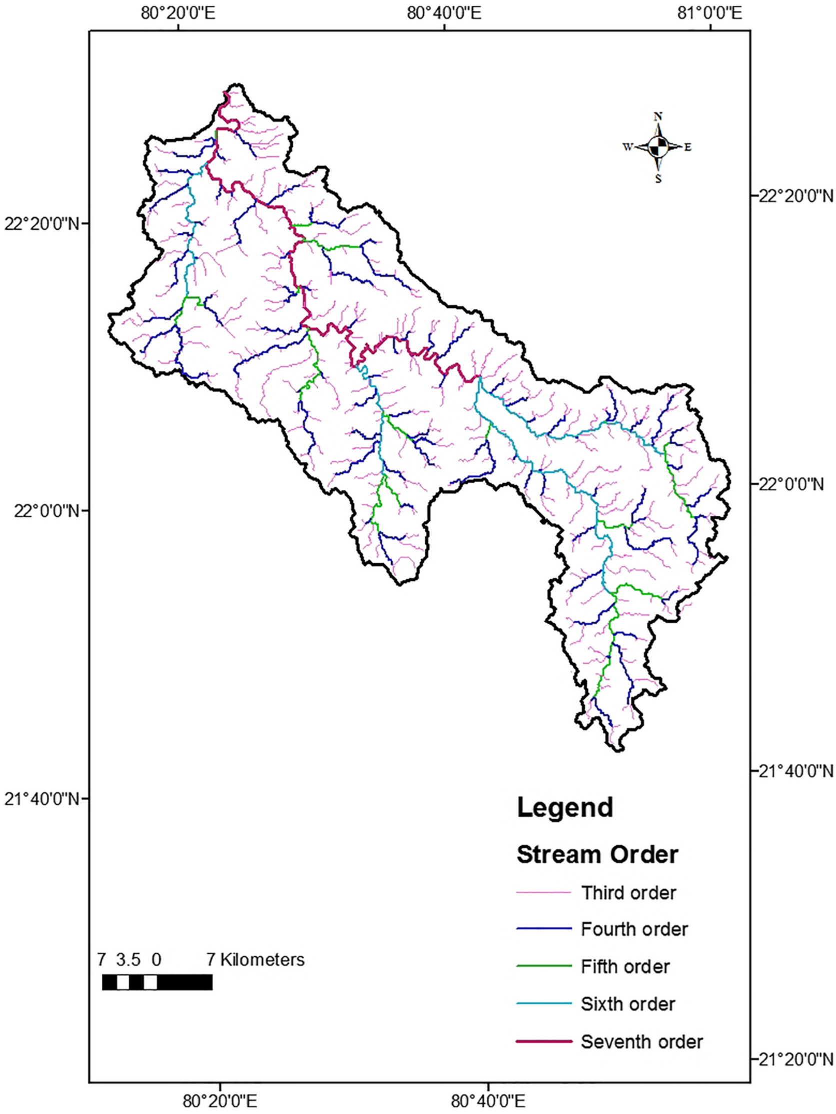

Fig. 2 Drainage pattern of the study area

sub-watershed, and then compared. Afterward, the order preference of sub-watersheds were determined by the ELECTRE and VIKOR models. For the watershed prioritization, a number of 14 geo-morphometric values were considered at the sub-watershed level.

2.3 Multi-Criteria Decision Making (MCDM) Techniques

MCDM is a group of procedures that are used to evaluate a set of alternatives regarding numerous decision criteria, which result in disagreement in many cases (Zavadskas et al. 2014). Thus, considering a collection of processes and numerous ground of judgment, MCDM provides not only an alternative, hierarchy, categorization, and arrangement, but also, in most

Table 1 Formulae for computation of morphometric parameters

Morphometric parameters	Formula	Reference
Stream Order (u)	Hierarchical rank	Strahler (1964)
Stream Length (Lu)	Length of the stream	Horton (1945)
Mean Stream Length (Lsm)	$Lsm = Lu/Nu$ where Lsm = Mean stream length Lu = Total stream length of Order u Nu = Total number of stream segment of order u	Strahler (1964)
Bifurcation ratio (R_b)	$R_b = Nu/N_{u+1}$ where, Rb = Bifurcation Ratio Nu = Total number of stream segment of order u N_{u+1} = Number of stream segment of next higher order	Schumm (1956)
Mean Bifurcation ratio (R_{bm})	R_{bm} = average of bifurcation ratio of all orders	Strahler (1964)
Basin length (L_b)	$L_b = 1.312 * A^{0.568}$ where, L_b = length of basin (km) A = area of Basin (km^2)	Nookaratnam et.al (2005)
Drainage Density (D_d)	$D_d = Lu/A$ Where D_d = Drainage density Lu = Total stream length of all order A = Area of the basin	Horton (1945)
Stream Frequency (Fs)	$Fs = Nu/A$ where Nu = Total number of stream of all order A = Area of the basin (km^2)	Horton (1945)
Texture Ratio (T)	$T = Nu/P$ where Nu = Total number of stream of all order P = Perimeter (km)	Horton (1945)
Form Factor (Rf)	$Rf = A/{L_b}^2$ Where Rf = Form factor A = area of the basin (km^2) ${L_b}^2$ = Square of the basin length	Horton (1945)
Circulatory Ratio (Rc)	$Rc = 4\pi A/P^2$ where Rc = Circularity ratio A = Area of the basin (km^2) P = Perimeter (km)	Miller (1953)
Elongation Ratio (Re)	$Re = (2/L_b)*(A/\pi)^{0.5}$ Where Re = Elongation Ratio L_b = length of basin (km) A = Area of the basin (km^2)	Schumm (1956)
Compactness Constant (Cc)	$Cc = 0.2821P/A^{0.5}$ Where Cc = Compactness Ratio A = Area of the basin (km^2) P = Perimeter of the basin (km)	Horton (1945)
Length of Overland Flow (Lo) (km)	$L_o = 1/2D_d$ Where D_d = Drainage density	Horton (1945)
Relief ratio (R_h)	$R_h = H/L_b$ where H = Total relief of the watershed L_b = Maximum length of the watershed	Schumm (1956)
Relief relief (R_r)	$R_h = H/L_p$ where H = Total relief of the watershed L_p = Perimeter of the watershed	Schumm (1956)
Ruggedness number (R_N)	$R_N = H*D_d$ where H = Total relief of the watershed D_d = Drainage density	Moore et al. (1993)
Average slope of watershed (Sa)	$Sa = H*L_{ca}/10*A$ where H = Total relief of the watershed L_{ca} = Average length of all contours	Nautiyal (1994)

Table 1 (continued)

Morphometric parameters	Formula	Reference
	A = Watershed area	
Hypsometric Integral (HI)	HI = ($Elev_{mean}$-$Elev_{min}$)/ ($Elev_{max}$-$Elev_{min}$) Where $Elev_{mean}$, $Elev_{min}$ and $Elev_{max}$ are the mean, minimum and maximum elevations	Langbein (1947)

cases, an order of array descending from the most favorable choice (Liou and Tzeng 2012). Based on the ground of judgment, MCDM problems are frequently categorized as discrete or continuous (Zanakis et al. 1998). Another classification of MCDM methods might be possible by betting on their counteractive or non-compensatory nature. The former alters specific tradeoffs among criteria whereas the latter are principally based mostly on the comparison of alternatives with respect to individual criteria.

Therefore, we prioritized the sub-watersheds of Bamhani watershed for soil erosion using evaluation criteria (morphometric parameters) and multi-criteria decision-making methods (ELECTRE and VIKOR) in this research. For this purpose, the decision matrix D was first composed of using 20 options (sub-watersheds) and 14 indicators (morphometric parameters). The steps of each method are briefly explained.

2.3.1 ELECTRE

ELECTRE, The ELimination Et Choix Traduisant laREalit'e (elimination and choice expressing reality) method is one of the most important compensatory techniques. The application of this method is based on the concept of non-rank relationships (Ishizaka and Nemery 2013). The procedures of ELECTRE method are presented in seven steps (Abdolazimi et al. 2015):

Step 1: Formation of the normalization decision matrix (N_D):

The decision matrix D was transformed to a normalization matrix (N_D) with a Euclidean distance.

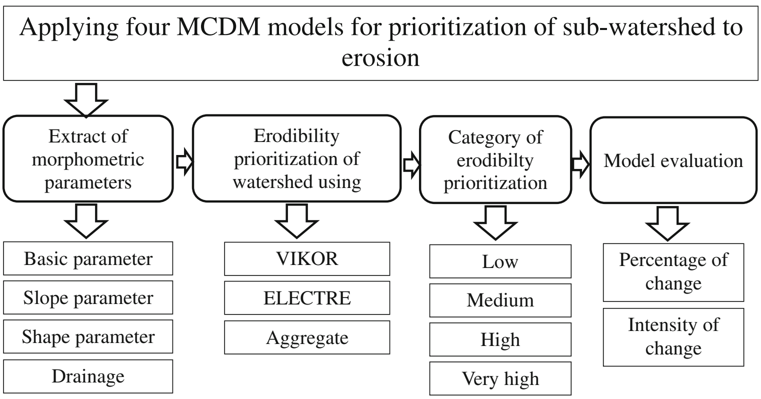

Fig. 3 Flowchart of the methodology used

$$D = \begin{matrix} SW_1 \\ SW_2 \\ \vdots \\ SW_m \end{matrix} \begin{bmatrix} X1 & X2 \ \ldots & Xn \\ x_{11} & x_{12} \ldots & x_{1n} \\ x_{21} & x_{22} \ldots & x_{2n} \\ \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} \ldots & x_{mn} \end{bmatrix}$$

The decision matrix is normalized as:

$$N_D = [r_{ij}], r_{ij} = \frac{x_{ij}}{\left(\sum_{i=1}^{m} x_{ij}{}^2\right)^{1/2}} \quad i = 1, 2, \ldots\ldots\ldots, m \ \ and \ \ j = 1, 2, \ldots\ldots\ldots\ldots, n \tag{1}$$

Where x_{ij} represents the value of j-attribute (morphometric parameters) for i-alternative (sub-watershed), and r_{ij} represents the value of the new normalized decision-making matrix (N_D).

Step 2: Calculation of the normalization weighted matrix.

In this step, normalization weighted matrix is obtained using a W-diagonal matrix.

$$V = N_D \times W_{n \times n} \tag{2}$$

Where V is a normalization weighted matrix and W is a diagonal matrix of estimated weights for each of the indicators (morphometric parameter).

Step 3: Forming a collection of harmonious and incoherent:

The harmonious and incoherent set is formed according to Eqs. 3 and 4.

$$\text{Harmonious} \begin{cases} S_{ki} & = \{j | r_{kj} \geq r_{ij}\} \\ S_{ki} & = \{j | r_{kj} \leq r_{ij}\} \end{cases} \tag{3}$$

$$\text{Incoherent} \begin{cases} D_{ki} & = \{j | r_{kj} < r_{ij}\} \\ D_{ki} & = \{j | r_{kj} > r_{ij}\} \end{cases} \tag{4}$$

Where D_k: incoherent collection and S_k: harmonious collection.

Step 4: Formation of harmonious matrix.

The harmonious matrix is a matrix of dimensions $m \times m$ and can be estimated using Eq. 5.

$$I_{ki} = \sum w_j \qquad I = \begin{vmatrix} - & I_{1,2} & I_{1,3} & \cdots & \cdots & I_{1,m} \\ I_{2,1} & - & I_{2,3} & \cdots & \cdots & I_{2,m} \\ \vdots & \vdots & \vdots & \cdots & \cdots & \vdots \\ \vdots & \vdots & - & - & \cdots & \vdots \\ \vdots & \vdots & . & \vdots & - & \vdots \\ I_{m,1} & I_{m,2} & \cdots & \cdots & I_{m(m-1)} & - \end{vmatrix} \tag{5}$$

Step 5: Formation of incoherent matrix

An incoherent matrix is defined by NI, which is a matrix m × m and is estimated using Eq. 6.

$$NI_{ki} = \frac{MAX\left|V_{ki} - V_{ij}\right|, \quad j \in D_{ki}}{MAX\left|V_{ki} - V_{ij}\right|, \quad j \in J} NI = \begin{vmatrix} - & NI_{1,2} & NI_{1,3} & \cdots & \cdots & NI_{1,m} \\ NI_{2,1} & - & NI_{2,3} & \cdots & \cdots & NI_{2,m} \\ \vdots & \vdots & \vdots & \cdots & \cdots & \vdots \\ \vdots & \vdots & - & - & \cdots & \vdots \\ \vdots & \vdots & . & \vdots & - & \vdots \\ NI_{m,1} & NI_{m,2} & \cdots & \cdots & NI_{m(m-1)} & - \end{vmatrix} \tag{6}$$

Formation of harmonious effective and incoherent effective matrix.

In this step, the threshold is estimated according to Eqs. 7 and 8.

$$\bar{I} = \frac{\sum_{i=1}^{m}\sum_{k=1}^{m} I_{k,i}}{m(m-1)} F_{ki} = \begin{cases} 1 & I_{ki} \geq \bar{I} \\ 0 & I_{ki} < \bar{I} \end{cases} \tag{7}$$

$$\overline{NI} = \frac{\sum_{i=1}^{m}\sum_{k=1}^{m} NI_{k,i}}{m(m-1)} G_{ki} = \begin{cases} 1 & NI_{ki} \geq \overline{NI} \\ 0 & NI_{ki} < \overline{NI} \end{cases} \tag{8}$$

Step 6: Formation of general and effective matrix.

In the final step, a general and effective matrix is constructed using Eq. 9.

$$H_{ki} = F_{ki} \times G_{ki} \tag{9}$$

2.3.2 VlseKriterijumska Optimizcija I Kaompromisno Resenje in Serbian (VIKOR)

The VIKOR method is an important tool in MCDM and is used to solve problems linked to compatible and incompatible standards (Opricovic and Tzeng 2004). The procedures of VIKOR are presented in the following four steps (Opricovic and Tzeng 2004).

Step 1: Generating the normalization decision matrix (F):

The decision matrix D was changed to a normalization matrix (F) using Eq. 10.

$$D = \begin{array}{c} \\ SW_1 \\ SW_2 \\ \vdots \\ SW_m \end{array} \begin{array}{c} X1 \quad X2 \quad \dots \; Xn \\ \begin{bmatrix} x_{11} & x_{12}\dots & x_{1n} \\ x_{21} & x_{22}\dots & x_{2n} \\ \vdots \quad \vdots & \vdots & \vdots \\ x_{m1} & x_{m2}\dots & x_{mn} \end{bmatrix} \end{array}$$

$$R_{ij} = \frac{x_{ij}}{\sum_1^m x_{ij}} \tag{10}$$

$$F = \begin{array}{c} \\ SW_1 \\ SW_2 \\ \vdots \\ SW_m \end{array} \begin{array}{c} X1 \quad X2 \quad \dots \; Xn \\ \begin{bmatrix} f_{11} & f_{12}\cdots & f_{1n} \\ f_{21} & f_{22}\cdots & f_{2n} \\ \vdots & \vdots \quad \vdots & \vdots \\ f_{m1} & f_{m2}\cdots & f_{mn} \end{bmatrix} \end{array}$$

Where x_{ij}indicates the value of *j*-attribute (morphometric parameter) for *i*-alternative (sub-watershed), f_{ij} indicates the value of new normalized decision-making matrix (F).

Step 2: Calculation of criteria weight. In this analysis, the weight of each criterion was determined in Expert Choice software using the AHP (Analytical Hierarchy Process) method (Ren et al. 2015). AHP is based on pair-wise comparisons and is given its description in Saaty (1977).

Step 3: Computing a weighted normalised matrix by multiplying the usual matrix in each criterion 's weight as an Eq. (11) (Huang et al. 2009; Sanayei et al. 2010):

$$f_{ij} = R_{ij} {*} w_j \tag{11}$$

where, f_{ij} is weighted normalized decision matrix element, R_{ij} is a normalized decision matrix element, and w_j is weight of criteria calculated using the AHP model.

Step 4: Determine the best and worst of the available values for each criterion.

In the VIKOR method, after generating the decision matrix, Eqs. 12 and 13 are used to determine the best and worst values among the available morphometric parameters,

$$f_i^- = min_j\, f_{ij},\;\; f_i^* = max_j f_{ij} \tag{12}$$

$$f_i^* = min_j\, f_{ij},\;\; f_i^- = max_j f_{ij} \tag{13}$$

Where f_i^* and f_i^- are the best and the worst values, respectively.

Morphometric parameters	Best	Worst
Positive parameters	$f_i^* = max_j\, f_{ij}$	$f_i^- = min_j\, f_{ij}$
Negative parameters	$f_i^* = min_j\, f_{ij}$	$f_i^- = max_j\, f_{ij}$

Step 5: Calculation of maximum group utility of the majority (S) and minimum individual regret of the opponent (R):

In this step, Eqs. 14 and 15 are used to calculate the maximum group utility of the majority (S) and minimum individual regret of the opponent (R).

$$S_j = \sum_{i=1}^{n} w_i \left(f_i^{\,*} - f_{ij}\right) / \left(f_i^{\,*} - f_i^{\,-}\right) \quad (14)$$

$$R_j = max_i \left[w_i \left(f_i^{*} - f_{ij}\right) / \left(f_i^{*} - f_{ij}\right) \right] \quad (15)$$

Where w_i is the morphometric parameter's weight.

Step 4: Calculation of the VIKOR indicator for each alternative.

In this step, Q as a compromise solution for R and S, otherwise known as the advantage function, is eventually calculated from Eq. 16. At last, ranking and nomination of sub-basins were carried out.

$$Q_j = V\left(S_j + S^{+}\right)/\left(S^{-} - S^{+}\right) + (1 - V)\left(R_j - R^{+}\right)/\left(R^{-} - R^{+}\right) \quad (16)$$

Where$S^{+} = Min_j S_j$,$S^{-} = Max_j S_j$, $R^{+} = Min_j R_j$, $R^{-} = Max_j R_j$ and V is the weight determined by the maximum group consensus.

2.4 Compound Factor

During prioritization of sub-watersheds, morphometric parameters are being used, which are also named as erosion hazard assessment parameter. As indicated in the previous studies (i.e., Biswas et al. 2002; NookaRatnam et al. 2005; Thakker and Dhiman 2007), the highest values of linear parameters (such as texture ratio, length of overland flow, stream frequency, drainage density and average slope) of sub-watersheds were assigned to rank 1 for the highest value and to rank 2 for the next highest value and so on as soil erosion hazard from the above parameters shows positive correlation to them. However, the least value was assigned to the lowest rank in the order of priority. The lowest values of shape parameters (i.e., circulatory ratio, elongation ratio and form factor) of respective sub-watersheds were ranked as the top and so on as soil erosion hazard from the above parameters showed negative correlation to them (Gajbhiye et al. 2014). Having the ranks based on the morphometric parameters used in this study, all assigned ranks were summed up and divided by all the morphometric parameters used for Bamhani watershed to determine the compound factor (CF).

The sub-watershed with lowest CF receives the highest priority, meaning that being most vulnerable to soil erosion hazard. The next highest value gets the second priority and henceforth. Consequently, the sub-watershed, which was associated with the highest priority, requires immediate attention to implement soil conservation treatments and onwards.

2.5 Validation of Models

To evaluate the results and compare the models with each other, Eqs. 17 and 18 can be adopted for the percentage of change and intensity of change, respectively (Badri 2003):

$$\Delta P = \frac{N - N_{canstant}}{N} \times 100 \quad (17)$$

Table 2 Computation of basic parameters for Bamhani watershed in the GIS environment

Sub-watershed	Area (km^2)	Perimeter (km)	Elevation Max (m)	Elevation Min (m)	Length of basin (km)	Total Relief (m)	No. of Streams	Total Stream Length (km)
BM 1	91.15	60.72	640	460	15.60	180	363	227.71
BM 2	23.38	18.56	520	460	5.07	60	61	33.07
BM 3	40.56	24.69	640	480	7.13	160	115	71.42
BM 4	155.74	68.69	860	460	21.16	400	615	368.91
BM 5	83.48	48.80	660	500	9.40	160	330	201.16
BM 6	337.16	110.11	660	460	23.64	200	1403	817.56
BM 7	111.52	57.64	640	540	12.83	100	435	264.52
BM 8	38.08	26.79	700	560	7.76	140	119	73.96
BM 9	31.93	24.32	840	620	6.45	220	100	59.15
BM 10	101.02	59.28	860	600	11.83	260	465	265.30
BM 11	533.29	171.84	900	520	37.30	380	2033	1329.90
BM 12	71.73	39.95	700	540	11.08	160	287	176.92
BM 13	137.52	74.71	860	520	18.01	340	546	338.95
BM 14	31.76	24.58	700	560	8.00	140	100	57.18
BM 15	267.03	108.51	760	560	31.11	200	1103	653.99
BM 16	98.15	61.47	860	620	16.02	240	371	224.50
BM 17	81.42	45.78	800	560	13.87	240	323	201.53
BM18	97.70	56.75	720	580	11.33	140	394	235.24
BM 19	43.68	35.12	760	600	8.57	160	139	82.37
BM 20	165.86	76.67	760	600	19.96	160	704	424.64

$$\Delta I = \frac{\sum_{I=1}^{N} \frac{rank\ i\ (r1)}{rank\ i\ (r2)}}{N} \quad (18)$$

Where ΔP represents the percentage of change as N does the total number of sub-basins. $N_{canstant}$ is the number of sub-bases that are ranked in comparison with the two methods, ΔI is the intensity of change, rank i (r1) represents the sub-basin i in the first method, and rank i (r2) represents the sub-basin i in the second method.

3 Results and Discussion

3.1 Morphometric Analysis

Stream ordering is the preliminary step in any morphometric analysis. In our study, an approach proposed by Strahler (1964) has been used to identify ordering of stream for 20 sub-watersheds in the study domain (Fig. 1).

3.2 Basic Parameters

In GIS environment parameters such as number of stream with their lengths, watershed area with its length and perimeter in each watershed were determined. Table 2 shows sub-watershed related morphometric parameters in Bamhani watershed, which is here after abbreviated as BM. It is evident

Table 3 Sub-watershed wise geomorphological parameters of Bamhani watershed

Sub- watershed	R_h	R_r	R_N	R_b	D_d	F_s	R_c	R_f	R_e	T	L_o	C_c	S_a	HI
BM 1	0.012	0.003	0.450	3.485	2.498	3.983	0.313	0.375	0.691	5.979	0.200	0.024	3.871	0.500
BM 2	0.012	0.003	0.148	2.917	1.415	2.609	0.859	0.910	0.989	3.287	0.353	0.052	2.160	0.500
BM 3	0.022	0.006	0.374	3.792	2.337	3.764	0.634	0.601	0.875	4.658	0.214	0.046	4.027	0.500
BM 4	0.019	0.006	0.948	3.662	2.369	3.949	0.418	0.348	0.666	8.954	0.211	0.015	8.519	0.500
BM 5	0.017	0.003	0.386	3.432	2.410	3.953	0.443	0.945	0.987	6.762	0.208	0.024	4.676	0.485
BM 6	0.008	0.002	0.485	4.676	2.425	4.161	0.352	0.603	0.877	12.742	0.206	0.009	4.538	0.500
BM 7	0.008	0.002	0.237	4.353	2.372	3.901	0.425	0.677	0.929	7.547	0.211	0.019	2.387	0.500
BM 8	0.018	0.005	0.369	4.889	1.942	3.125	0.671	0.632	0.898	4.441	0.257	0.038	4.428	0.500
BM 9	0.034	0.009	0.593	3.167	1.852	3.132	0.683	0.767	0.989	4.112	0.270	0.044	6.229	0.500
BM 10	0.022	0.004	0.683	4.945	2.626	4.603	0.364	0.722	0.959	4.475	0.190	0.022	6.647	0.565
BM 11	0.010	0.002	0.948	5.657	2.494	3.812	0.228	0.383	0.699	11.831	0.201	0.007	6.467	0.500
BM 12	0.014	0.004	0.395	3.846	2.466	4.001	0.568	0.584	0.863	7.184	0.203	0.025	5.045	0.500
BM 13	0.019	0.005	0.838	3.588	2.465	3.970	0.312	0.424	0.735	7.309	0.203	0.018	5.796	0.500
BM 14	0.018	0.006	0.368	2.971	1.800	3.148	0.665	0.496	0.795	4.068	0.278	0.044	3.791	0.500
BM 15	0.006	0.002	0.490	4.101	2.449	4.131	0.287	0.276	0.593	10.165	0.204	0.011	4.621	0.500
BM 16	0.015	0.004	0.591	4.096	2.287	3.780	0.329	0.382	0.698	6.035	0.219	0.023	6.801	0.500
BM 17	0.017	0.005	0.594	4.015	2.475	3.967	0.491	0.423	0.734	7.055	0.202	0.023	9.125	0.500
BM 18	0.012	0.002	0.337	3.867	2.408	4.033	0.384	0.761	0.985	6.943	0.208	0.022	3.731	0.500
BM 19	0.019	0.005	0.391	3.329	1.886	3.182	0.448	0.595	0.870	3.958	0.265	0.038	6.139	0.595
BM 20	0.008	0.002	0.410	4.927	2.560	4.245	0.357	0.416	0.728	9.182	0.195	0.015	5.040	0.595

Table 4 Priority ranking of the sub-watersheds (Bamhani watershed)

Sub basin Name	Score based on VIKOR	Prioritization Ranks based on VIKOR	Prioritization Ranks based on ELECTRE
BM-1	0.67985	11	8
BM-2	0.50000	16	12
BM-3	0.338161	17	10
BM-4	0.87548	5	2
BM-5	0.503418	15	10
BM-6	0.877431	4	4
BM-7	0.748917	8	9
BM-8	0.31023	18	8
BM-9	0.02945	20	9
BM-10	0.82473	7	5
BM-11	1	1	1
BM-12	0.58237	14	7
BM-13	0.668769	12	6
BM-14	0.212678	19	11
BM-15	0.9327	3	5
BM-16	0.641047	13	6
BM-17	0.827568	6	2
BM-18	0.732463	9	9
BM-19	0.710696	10	9
BM-20	0.951469	2	3

in Table 2 that BM 2 covers an area of 23.38 km^2, which is the smallest sub-watershed whereas BM 11 has the area (533.29 km^2) among 20 sub-watersheds. The large length of higher order stream is also an indication of permeable topography and formation. An average stream length of higher order stream of sub-watersheds varies from 1.95 km (BM 9) to 43.68 km (BM 11). Therefore, BM 9is said to have a resistant topography as BM 11 has a permeable topography and formation conditions.

3.3 Shape Parameters

The basin shape affects the discharge characteristics (i.e., streamflow hydrograph) and could be characterized through shape parameters (i.e., circulatory ratio, form factor and elongation ratio). These metrics of sub-basins in our study revealed that BM 2, 3, 8, 9, 12, 14, and 17 are circular whereas BM 4, 5, 7 and 19 are less elongated, and BM 1, 6, 10, 11, 13, 15, 16, 18, and 20 are elongated in shape (Table 3). In an elongated basin, the streamflow hydrograph emerges smoother in shape, meaning that a longer time is required for surface water travelling from the most upstream point to the outlet point. However, the case gets worse for a circular basin because surface water flowing down from all parts of the basin arrives to the outlet point in less time, causing an excessive peak value. The compactness coefficient was computed as0.007 and 0.046 for BM11 and 3, respectively, implying that the latter is more compact than the former.

3.4 Drainage Parameters

Among the linear parameters, the drainage density is very important parameter and has a relation with the stream length and watersheds area. Table 3 shows respective drainage density of sub-watersheds of Bamhani at which BM 20 possesses the highest value ($D_d = 2.560$ km/km^2) whereas BM 2 possesses the lowest drainage value ($D_d = 1.415$ km/km^2). Moreover, a large group of BM 1, 3, 4, 5, 6, 7, 10, 11, 12, 13, 15, 16, 17 and 18 have D_d in the same range

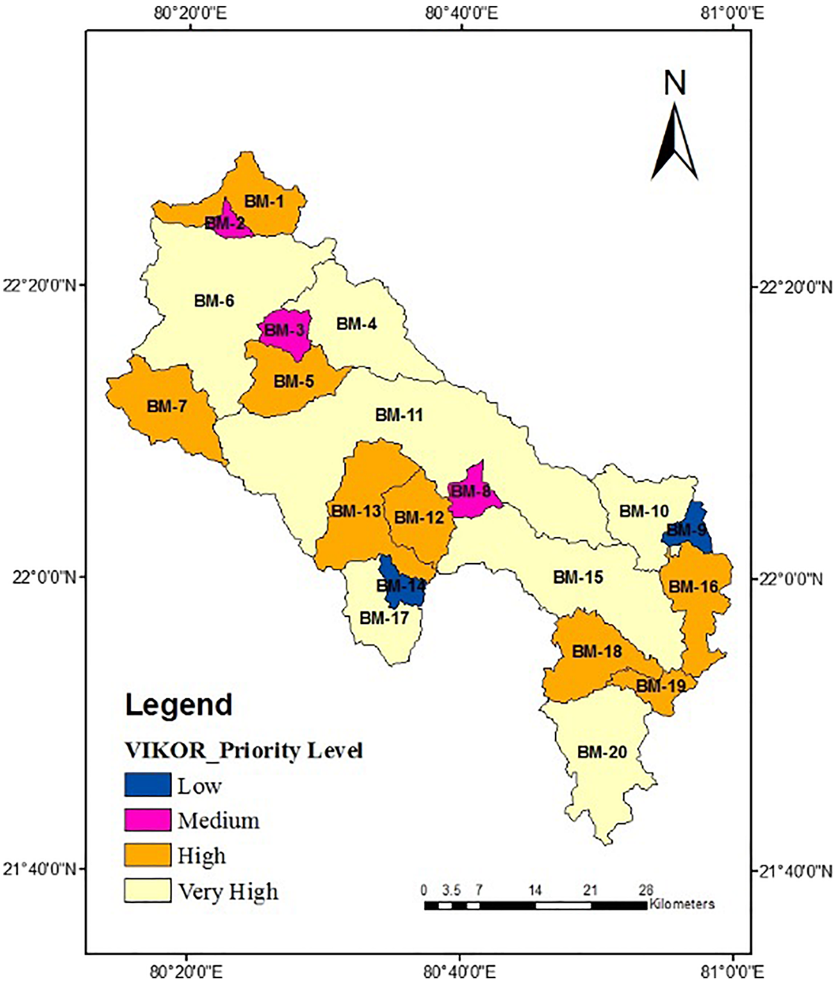

Fig. 4 Classification of sub-watersheds to erodibility using VIKOR method.

as BM 20. On the other hand, the remaining of BM 8, 9, 14 and 19 have D_d value in the same range as of BM 2, which shows permeable sub-soil conditions indicated by its low D_d value. The BM 20 having the highest D_d value among all the sub-basins can be linked up with a well-developed drainage network. In this case, severe rainfall regimes constitute extreme floods whereas a high D_d value refers rapid spread of runoff, existence of fragile material at substrata, high elevation, and scattered vegetation (Nautiyal 1994).

The values of frequency of stream (F_s) in some sub-basins vary from 2.609 to 4.603 no./km. These limits were observed in the sub-basins 2 and 10, respectively. A high stream frequency value corresponds to a good channel development. The intensity of erosion in a watershed increases with the stream frequency, which is positively correlated with the drainage density. In addition, the texture ratio (T) of sub-basins ranged from 3.287 in BM 2 to 11.831 in BM 11.

Table 5 Erodibility prioritization of sub-watersheds by compound factor method (CF)

Sub- watershed	Rh	Rr	RN	Rb	Dd	Fs	Rc	Rf	Re	T	Lo	Cc	Sa	HI	CF	Rank
BM 1	8	3	9	15	3	7	17	3	3	13	15	10	16	3	8.93	9
BM 2	8	3	19	20	20	20	1	19	19	20	1	16	20	3	13.50	15
BM 3	2	2	14	12	14	15	5	12	12	14	7	15	15	3	10.14	10
BM 4	3	2	1	13	13	11	11	2	2	5	8	4	2	3	5.71	1
BM 5	5	3	13	16	10	10	9	20	18	11	9	10	11	4	10.64	13
BM 6	10	2	8	5	9	3	15	13	13	1	10	2	13	3	7.64	6
BM 7	10	2	18	6	12	12	10	15	15	6	8	7	19	3	10.21	11
BM 8	4	3	15	4	16	19	3	14	14	16	5	12	14	3	10.14	10
BM 9	1	1	5	18	18	18	2	18	19	17	3	14	6	3	10.21	11
BM 10	2	4	3	2	1	1	13	16	16	15	17	8	4	2	7.43	5
BM 11	9	2	1	1	4	13	20	5	5	2	14	1	5	3	6.07	2
BM 12	7	4	11	11	6	6	6	10	10	8	12	11	9	3	8.14	8
BM 13	3	3	2	14	7	8	18	8	8	7	12	6	8	3	7.64	6
BM 14	4	2	16	19	19	17	4	9	9	18	2	14	17	3	10.93	14
BM 15	11	2	7	7	8	4	19	1	1	3	11	3	12	3	6.57	4
BM 16	6	4	6	8	15	14	16	4	4	12	6	9	3	3	7.86	7
BM 17	5	3	4	9	5	9	7	7	7	9	13	9	1	3	6.50	3
BM 18	8	2	17	10	11	5	12	17	17	10	9	8	18	3	10.50	12
BM 19	3	3	12	17	17	16	8	11	11	19	4	13	7	1	10.14	10
BM 20	10	2	10	3	2	2	14	6	6	4	16	5	10	1	6.50	3

3.5 Slope Parameters

The difference of elevation in most remote point of watershed and its outlet is known as total relief (H) that ranged between 460 m and 900 m in Bamhani watershed, considering all sub watersheds. The relief ratio (R_h) can be defined as potential energy measure to move the water and sediment downward, whose range varies from 0.006 to 0.034 in our study. The lowest limit of R_h was observed in BM 15 as the highest limit in BM 9. As the relief ratio parameter increases, the erosion intensity can be expected more in the sub-basin. The range of relative relief (R_r) was determined between 0.002 (BM 15) and 0.009 (BM 9). At the same time, the ruggedness number (R_N) was calculated as 0.148 for BM 2 being the lowest value and as 0.948 for BM 4 being the highest value in our study. It is important to note that any sub-basin with high ruggedness number is thought to be apt to extensive soil erosion. The average slope of the basin was found to be between 2.160% (BM 2) and 8.519% (BM 4). Hypsometric integral analysis shows that all the sub-watersheds is in equilibrium stage.

3.6 Erodibility Criteria for Sub-Watershed Prioritization by ELECTRE and VIKOR Models

Prioritization of watershed can be described as the procedure of ranking of different sub-basins in an order at which they could be considered in the sense of soil conservation measures. Therefore, a practical approach to prioritize the sub-basins appears to be a need for further steps. The highest values of linear relief parameters (namely, relative relief, relief ratio, and ruggedness number) and average slope of sub-watersheds were associated with top ranks among 14 sub-watersheds of Bamhani watershed. It is worthwhile to remind that the geomorphological parameters are generally correlated with soil erosion positively as noted by Biswas et al. (2002) and Thakker and Dhiman (2007). Following Gajbhiye et al. (2014), we here rank

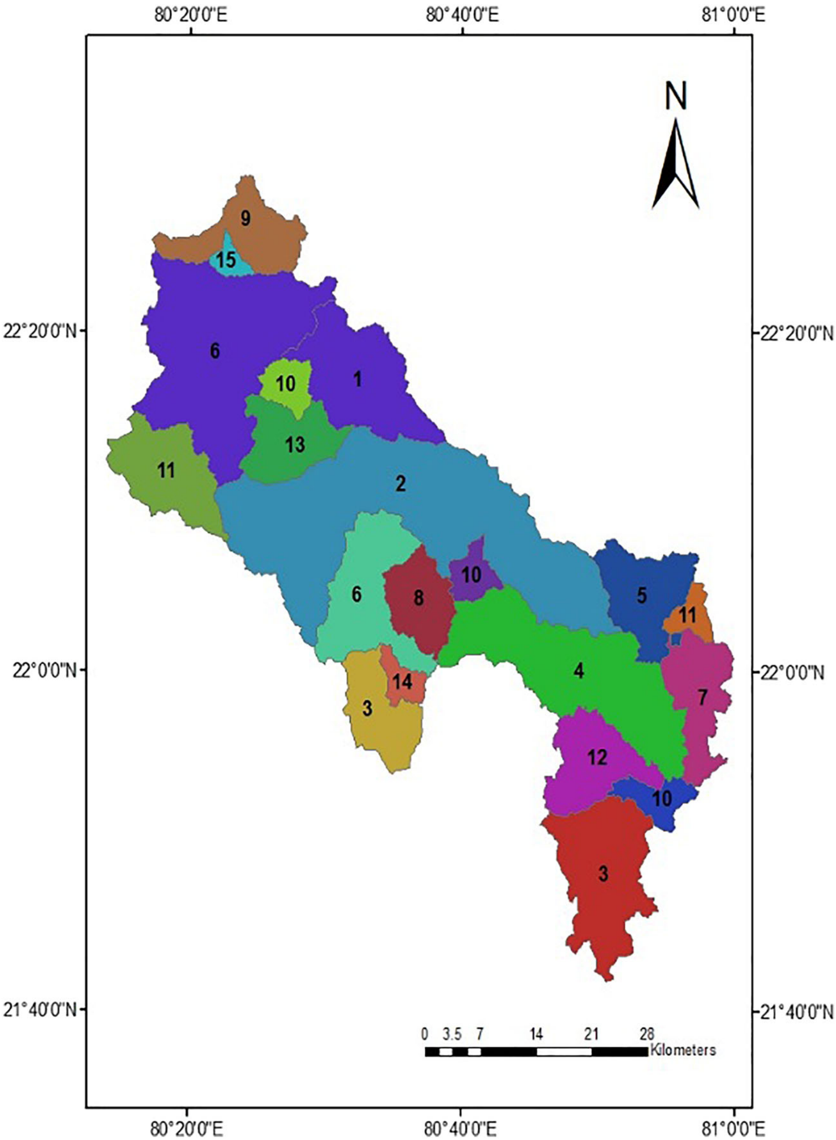

Fig. 5 Prioritization of sub-watersheds using the compound method

Table 6 Priority level

S. No.	Priority Levels	Priority Types	Sub-watersheds (VIKOR)
1	0–0.25	Low	BM-14, BM-9
2	0.25–0.50	Medium	BM-2, BM-3, BM-8,
3	0.50–0.75	High	BM-7, BM-18, BM-19, BM-1,BM-13, BM-16, BM-12, BM-5
4	0.75–1	Very High	BM-11, BM-20, BM-15, BM-6, BM-4, BM-17, BM-10

Table 7 Intensity of changes

Method	VIKOR method	ELECTRE method	CF method	Total changes
VIKOR method	1	1.572	1.505	4.077
ELECTRE method	1.572	1	1.401	3.973
CF method	1.505	1.401	1	3.906

the lowest value of sub-watersheds as 1 and 2 to the next lowest value and so on for the shape parameters, which all are negatively correlated with soil erosion.

The MCDM approach does not offer values for evaluating any alternative. The outcome of the method only indicates the alternative has prevailed (outranked the others) by a pairwise comparisons. The findings of both sample groups, as well as the aggregate performance, confirm that scenario is the most suitable management technique. A significant approach statistical is the distribution of the weightings of each criterion (Table 4). The popular questionnaire of the ELECTRE and VIKOR methods resulted in this ranking, so the following statistics are descriptive for the VIKOR method as well.

We determined morphometric parameters (Table 3) and developed a matrix that specifies the initial requirement in establishing multi-criteria decision making models. Hence the criteria set in our study is composed of different measurement units (i.e., slope, drainage density and stream frequency), we applied a normalization procedure in order to put our data on an equal footing. For the normalization of data, we used the linear method in the TOPSIS model by the vector method. Later the weights of the criteria were found to set up the weighted normalized decision matrix for the MCDM models.

After determining the weight of the criteria, the weighted normalized decision matrix was calculated for two MCDM models according to Eqs. 2 (ELECTRE) and 11 (VIKOR). Consequently, the best and worst values in VIKOR model (Eq. 12, 13) and effective solutions for ELECTRE model (Eq. 9). By the way, results of utility index, regret index, and ranking of sub-watersheds according to VIKOR model was done using Eqs. 14 to 16. Also, the final weights were determined in each sub-basin using the VIKOR and ELECTRE model (Table 4).

As a result of VIKOR model revealed that the sub-basins 11, 20 and 15 had the highest third scores (1, 0.951 and 0.933, respectively) and ranked at the top three orders. However, the opposite conclusions could be made for the sub-basins 9, 14 and 8 having respective scores of 0.029, 0.213 and 0.3102, which made them place in the lowest ranks. The former (latter) sub-basin group should be then thought to be most (least) vulnerable to erosion (Fig. 4). Finally, ELECTRE model resulted in similar results so that the sub-basins BM 11, BM 4, BM 17 and BM 20 were assigned to a rank between 1 to 4 whereas the sub-basins BM 2, BM 14, BM 3 and BM 5 were matched to the lowest ranks. Once again, the former (latter) sub-basin group should be then thought to be most (least) vulnerable to erosion.

Afterward the completion of ranking sub-basins phase, we classified them into four categories with respect to erosion and loss of natural resources: (i) low (0–0.25), (ii) moderate

Table 8 Percentage of changes

Method	VIKOR method	ELECTRE method	CF Method	Average of percentage of changes
VIKOR method	0	85	90	58.34
ELECTRE method	85	0	80	55.00
CF Method	90	80	0	56.66

(0.25–0.50), (iii) high (0.50–0.75), and (iv) very high (0.75–1) according to VIKOR model in this study, all the sub-basins were grouped in the three categories (like very high, high and moderate). The results are summarized in Table 7 and Fig. 4.

3.7 Erodibility-Based Prioritization of Sub-Watersheds by Compound Factor Method

A particular sub-watershed, which is thought to be exposed to erosion at most, is ranked first in terms of priority in the compound factor methods. In each sub-watershed, we also determined the compound factor (CF) values through aggregating all rankings of linear, shape, and slope parameters and then dividing them by the total number of parameters (Eq. 20). Patel et al. (2012) stated that a sub-watershed with the lowest CF can be ranked first in terms of priority, implying the highest erosion capacity. Table 5 summarizes the results of sub-watershed prioritization by the CF method. It is noted that the sub-watersheds BM 4, BM 11 and BM 17 with lower CF values (5.71, 6.07 and 6.50, respectively) were assigned to the rank 1 to 3. Nevertheless, the sub-watersheds BM 2, BM 5 and BM 14 containing higher respective CF values (13.50, 10.64 and 10.93) were listed at the bottom ranks (Fig. 5). The priority level of watershed (low, medium, high and very high) is shown in Table 6.

3.8 Validation of Models

Tables 7 and 8 present analysis results concerning evaluation of the methods using the percentage of change and intensity of change. Among the aforementioned three methods, VIKOR having a change percentage of 58.34 outperformed in terms of high efficiency and accuracy against its competitors of ELECTRE and CF whose percentage of changes were calculated as 55.00 and 56.66, respectively (Table 7).

From the standpoint of intensity of change, VIKOR model demonstrated the highest magnitude (4.077) comparison to the methods of ELECTRE and CF whose intensity of change values are 3.973 and 3.906, respectively (Table 8). An overall evaluation shows that the VIKOR model was found to be more applicable than the other models based on the percentage of change and the intensity of change.

4 Conclusion

Latest information technology tool (i.e. RS and GIS), helps in easy and quick estimation of morphometric parameters. However, DEM gives the drainage network parameters for quantitative geo-hydrology. Bamhani watershed was selected as a study domain and its morphometric parameters were determined in GIS environment and remote sensing tool used for updated drainage network, and prioritization of sub-watershed was done for easy and early development of sub-watersheds. The erosional processes of watershed are closely related to the morphology which is explained by linear relief and areal extend of watershed. Watershed prioritization helps us in making development and management plan of a watershed in a sustainable manner.

A group of ELECTRE, VIKOR and Aggregate strategy was utilized in making priority of sub-watershed with respect to soil erosion. Four categories, namely low, moderate, high and very high, were defined to evaluate erosion in the sub-watersheds. The outcomes of the superior method (VIKOR) revealed that portions of Bamhani watershed exposed to erosion are as follows: 63.69 km^2 (2.50%) was found in the category of low erosion hazard, 102.02 km^2 (4.01%) in the medium erosional susceptibility category, 734.93 km^2 (28.91%) in the high erosional susceptibility category, and finally 1641.36 km^2 (64.58%) in the class of very high erosional susceptibility category. Therefore, the high susceptibility category sub-watershed should be immediately undertaken adopting area specific soil and water conservation treatments. This study carries highly significant essence from a purely practical point of view of reducing the further chances of deterioration of land and water, which are vitally needed to feed the ever increasing population.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

References

Abdolazimi A, Momeni M, Montazeri M (2015) Comparing ELECTRE and linear assignment methods in zoning Shahroud-Bastam watershed for artificial recharge of groundwater with GIS technique. Mod Appl Sci 9(1):68–82. https://doi.org/10.5539/mas.v9n1p68

Amani M, Safaviyan A (2015) Sub-basins prioritization using morphometric analysis-remote sensing technique and GIS-Golestan-Iran. Int Lett Nat Sci 38:56–65. https://doi.org/10.18052/www.scipress.com/ILNS.38.56

Badri SA (2003) Models of rural planning. Pamphlets Practical Lesson in Geography and Rural Planning. Payame Noor University, p. 126

Biswas S, Sudhakar S, Desai VR (2002) Remote sensing and geographic information system based approach for watershed conservation. J Surv Eng 128(3):108–124. https://doi.org/10.1061/(ASCE)0733-9453(2002)128:3(108)

Chang CL, Hsu CH (2009) Multi-criteria analysis via the VIKOR method for prioritizing land-use restraint strategies in the Tseng-wen reservoir watershed. J Environ Manag 90:3226–3230. https://doi.org/10.1016/j.jenvman.2009.04.020

Chang CL, Lin YT (2014) Using the VIKOR method to evaluate the design of a water quality monitoring network in a watershed. Int J Environ Sci Technol 11:303–310. https://doi.org/10.1007/s13762-013-0195-2

Dahmardeh Ghaleno MR, Meshram SG, Alvandi E (2020) Pragmatic approach for prioritization of flood and sedimentation hazard potential of watersheds. Soft Comput. https://doi.org/10.1007/s00500-020-04899-4

Durbude DC, Purandara BK, Sharma A (2001) Estimation surface run-off potential of a watershed in semi-arid environment- a case study. J Indian Soc Remote Sens 29(1–2):47–58. https://doi.org/10.1007/BF02989914

Gajbhiye S, Mishra SK, Pandey A (2014) Prioritizing erosion-prone area through morphometric analysis: an RS and GIS perspective. Appl Water Sci 4:51–61. https://doi.org/10.1007/s13201-013-0129-7

Gajbhiye S, Sharma SK, Tignath S, Mishra SK (2015a) Development of a geomorphological Erosion index for Shakkar watershed. Geol Soc India 86(3):361–370

Gajbhiye S, Mishra SK, Pandey A (2015b) Simplified sediment yield index model incorporating parameter CN. Arab J Geosci 8(4):1993–2004

Gajbhiye S, Sharma SK (2017) Prioritization of watershed through morphometric parameters: a PCA based approach. Appl Water Sci 7:1505–1519. https://doi.org/10.1007/s13201-015-0332-9

Gioti E, Riga C, Kalogeropoulos K, Chalkias C (2013) A GIS-based flash flood runoff model using high resolution DEM and meteorological data. EARSeLe Proc 12:33–43

Huang JJ, Tzeng GH, Liu HH (2009) A revised VIKOR model for multiple criteria decision making - the perspective of regret theory. In Cutting-Edge Research Topics on Multiple Criteria Decision Making 35, pp. 761–768

Horton RE (1945) Erosional development of streams and their drainage basins: hydrophysical approach to quantitative morphology. Bull Geol Soc Am 56(275–3):70

Ishizaka A, Nemery P (2013) Multi-criteria decision analysis methods and software, John Wiley & Sons, Ltd, 2013

Khadse GK, Vijay R, Labhasetwar PK (2015) Prioritization of catchments based on soil erosion using remote sensing and GIS. Environ Monit Assess 187(6):333. https://doi.org/10.1007/s10661-015-4545-z

Kobryń A, Prystrom J (2015) A data pre-processing model for the Topsis method. Folia Oeconomica Stetinensia 16:219–235. https://doi.org/10.1515/foli-2016-0036

Langbein WB (1947) Topographic characteristic of drainage basins. USGS, WSP 968-C:127–157
Liou JJH, Tzeng GH (2012) Comments on "multiple criteria decision making (MCDM) methods in economics: an overview". Technol Econ Dev Econ 18:672–695. https://doi.org/10.3846/20294913.2012.753489
Liu C, Frazier P, Kumar L, Macgregor C, Blake N (2006) Catchment-wide wetland assessment and prioritization using the multi-criteria decision-making method TOPSIS. Environ Manag 38:316–326. https://doi.org/10.1007/s00267-005-0151-0
Mahmood SA, Yameen M, Sheikh R, Rafique AHM, Almas AS (2012) DEM and GIS based hypsometric analysis to investigate Neotectonic influence on Hazara Kashmir Syntaxis. Pak J Sci 64(3):209–213
Malekian A, Azarniv A (2016) Application of integrated Shannon's entropy and VIKOR techniques in prioritization of flood risk in the Shemshak watershed, Iran. Water Resour Manag 30:409–425. https://doi.org/10.1007/s11269-015-1169-6
Meshram SG, Alvandi E, Meshram C, Kahya E, Al-Quraishi AMD (2020) Application of SAW and TOPSIS in prioritizing watersheds. Water Resour Manag 34:715–732. 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
Meshram SG, Powar PL, Singh VP (2017) Modelling soil erosion from a watershed using cubic splines. Arab J Geosci 10:155–168. https://doi.org/10.1007/s12517-017-2908-1
Meshram SG, Powar PL, Meshram C (2018a) Comparasion of cubic, quadratic and Quintic splines for soil Erosion modelling. Appl Water Sci 8:173. https://doi.org/10.1007/s13201-018-0807-6
Meshram SG, Powar PL, Singh VP, Meshram C (2018b) Application of cubic spline in soil erosion modelling from Narmada watersheds, India. Arab J Geosci 11:362. https://doi.org/10.1007/s12517-018-3699-8
Meshram SG, Sharma SK (2017) Prioritization of watershed through morphometric parameters: a PCA-based approach. Appl Water Sci 7(3):1505–1519. https://doi.org/10.1007/s13201-015-0332-9
Miller VC (1953) A quantitative geomorphic study of drainage basin characteristics in the clinch mountain area, Virginia and Tennesses. Department of Navy, Office of Naval Res., Technical Report 3, Project NR 389–042, Washington DC
Ministry of Agriculture (1985) Statistics on soil and water conservation water management. Land resources and land reclamation in India (Ninth ed.). Ministry of Agriculture and co-operation, Soil and Water Conservation Division, Govt. of India, New Delhi
Mira MA, Ghazvinei PT, Sulaiman NMN, Basri NEA, Saheri S, Mahmood NZ, Jahan A, Begum RA, Aghamohammadi N (2016) Application of TOPSIS and VIKOR improved versions in a multi criteria decision analysis to develop an optimized municipal solid waste management model. J Environ Manag 166: 109–115. https://doi.org/10.1016/j.jenvman.2015.09.028
Moore ID, Gessler PE, Nielsen GAE, Peterson GA (1993) Soil attribute prediction using terrain analysis. Soil Sci Soc Am J. https://doi.org/10.2136/sssaj1993.572NPb
Mulliner E, Malys N, Maliene V (2016) Comparative analysis of MCDM methods for the assessment of sustainable housing affordability. Omega 59:146–156. https://doi.org/10.1016/j.omega.2015.05.013
Nautiyal MD (1994) Morphometric analysis of a drainage basin using arial photographs: a case study of Khairkuli basin, district Deharadun. J Indian Soc Remote Sens 22(4):251–262
NookaRatnam K, Srivastava YK, Venkateshwara Rao V, Amminedu E, Murthy KSR (2005) Check dam positioning by prioritization of micro-watersheds using SYI model and morphometric analysis—remote sensing and GIS perspective. J Indian Soc Remote Sens 33:25–38. https://doi.org/10.1007/BF02989988
Opricovic S, Tzeng GH (2004) Compromise solution by MCDM methods: a comparative analysis of VIKOR and TOPSIS. Eur J Oper Res 156:444–445. https://doi.org/10.1016/S0377-2217(03)00020-1
Patel DP, Srivastava PK, Gajjar CA (2012) Prioritization of Malesari mini-watersheds through morphometric analysis: a remote sensing and GIS perspective. Environ Earth Sci 69(8):2643–2656. https://doi.org/10.1007/s12665-012-2086-0
Raju KS, Kumar DN, Jalali A (2017) Prioritization of sub-catchments of a river basin using DEM and fuzzy VIKOR. H_2 Open Journal https://doi.org/10.2166/H2oj.2017.001
Ren J, Manzardo A, Mazzi A, Zuliani F, Scipioni A (2015) Prioritization of bioethanol production pathways in China based on life cycle sustainability assessment and multi-criteria decision making. Int J Life Cycle Assess 20:842–853. https://doi.org/10.1007/s11367-015-0877-8
Saaty TL (1977) A scaling method for priorities in hierarchical structures. J Math Psychol 15:59–62. https://doi.org/10.1016/0022-2496(77)90033-5
Salehi A, Izadikhah M (2014) A novel method to extend SAW for decision-making problems with interval data. Decis Sci Lett 3:225–234
Sanayei A, Mousavi SF, Yazdankhah A (2010) Group decision making process for supplier selection with VIKOR under fuzzy environment. Expert Syst Appl 37:24–30. https://doi.org/10.1016/j.eswa.2009.04.063

Schumm SA (1956) The evolution of drainage systems and slopes in bad lands at Perth, Amboi, New Jersey. Geol Soc Ame Bull 67(5):597–646

Shih HS, Shyur HJ, Lee ES (2007) An extension of TOPSIS for group decision making. Math Comput Model 45:801–813. https://doi.org/10.1016/j.mcm.2006.03.023

Shojaie AB, Babaie S, Sayah E, Mohammaditabar D (2017) Analysis and prioritization of green health suppliers using fuzzy ELECTRE method with a case study. Glob J Flex Syst Manag 19:39–52. https://doi.org/10.1007/s40171-017-0168-2

Strahler AN (1964) Quantitative geomorphology of drainage basins and channel networks. Section 4-II. In: Chow VT (ed) Handbook of applied hydrology. McGraw-Hill, PP, pp 4–39

Thakker AK, Dhiman SD (2007) Morphometric analysis and prioritization of mini-watersheds in Mohr watershed, Gujarat using remote sensing and GIS techniques. J Indian Soc Remote Sens 35(4):313–321. https://doi.org/10.1007/BF02990787

UNEP (1997) World atlas of desertification. 2nd edition Arnold London. 77

Yu X, Zhang S, Liao X, Qi X (2017) ELECTRE methods in prioritized MCDM environment. Inf Sci 424:301–316. https://doi.org/10.1016/j.ins.2017.09.061

Zanakis SH, Solomon A, Wishart N, Dublish S (1998) Multi-attribute decision making: a simulation comparison of select methods. European journal of. Oper Res 107:507–529. https://doi.org/10.1016/S0377-2217(97)00147-1

Zavadskas EK, Turskis Z, Kildienė S (2014) State of art surveys of overviews on MCDM/MADM. Technol Econ Dev Econ 20:165–179. https://doi.org/10.3846/20294913.2014.892037

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Affiliations

Sarita Gajbhiye Meshram[1,2] • Vijay P. Singh[3,4] • Ercan Kahya[5] • Ehsan Alvandi[6] • Chandrashekhar Meshram[7] • Shailesh Kumar Sharma[8]

[1] Department for Management of Science and Technology Development, Ton Duc Thang University, Ho Chi Minh City, Vietnam

[2] Faculty of Environment and Labour Safety, Ton Duc Thang University, Ho Chi Minh City, Vietnam

[3] Department of Biological and Agricultural Engineering, Texas A&M, University, College Station, TX 77843-2117, USA

[4] Zachry Department of Civil Engineering, Texas A&M University, College Station, TX 77843-2117, USA

[5] Civil Engineering Department, Istanbul Technical University (ITU), 34469 İstanbul, Türkiye

[6] Department of Watershed Management, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran

[7] Department of Post Graduate Studies and Research in Mathematics, Jayawanti Haksar, Government Post Graduation College, College of Barkatullah Vishwavidyalaya, Betul, M.P., India

[8] Department of Soil & Water Engineering, Jawaharlal Nehru Krishi Vishwa Vidyalaya Jabalpur, Jabalpur, India