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Application of SAW and TOPSIS in Prioritizing Watersheds

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Abstract
Prioritization of watersheds for conservation measures is essential for a variety of functions, such as flood control projects in which the determination of top priority areas is an important management decision. The purpose of this study is to examine watershed morphological characteristics and identify critical sub-watersheds, which are prone to be damaged, using Remote Sensing/Geographical Information Systems (GIS) and SAW/ TOPSIS (Simple Additive Weighting/ Technique for Order of Preference by Similarity to Ideal Solution). Fourteen morphometric parameters were chosen to organize sub-watersheds using SAW/TOPSIS, which examines sub-watersheds (as susceptible zones) from the perspective of classification in four priority levels (namely, low, moderate, high and very high levels). The SAW/TOPSIS approach is a useful strategy to find out potential zones provided that the ultimate goal is to achieve successful management strategies, particularly in particular zones where information accessibility is limited and soil assorted variety is high. Without facing with high cost and exercises in futility, sub-watersheds could be organized through morphometric parameters in executing conservational measures to save soil and the earth at the same time. In short, our results showed that morphometric parameters are highly efficient in identifying erosion-prone areas.

Keywords SAW · TOPSIS · RS and GIS · Morphometric parameters · Prioritization

1 Introduction

The total geographical area of India is 328 Mha (million hectares), of which 69 Mha area are critically degraded, and another 106 Mha area are seriously eroded. This endless soil erosion by numerous agents is a serious issue all around the world (Gajbhiye and Sharma 2017). It has been assessed that a total of 16.4 tones/ha of soil has been detached yearly in India due to

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various agents of destruction. India's land resources are under immense pressure since it comprises 2% of the earth geographical area (Singh, 2000).

The directly or indirectly morphometric parameters reflect nearly the entire watershed based causative variables influencing rainfall generated runoff and sediment. The surface highlights are the essential analysis units prior to adopting any sophisticated tool to monitor watershed responses in connection to any of hydrologic processes acting on it. Hence these parameters can be used as the basis for determination of watershed development priorities regarding proper soil and water management measures. Analysis of silt load data in India as well as in other parts of the world revealed that all watersheds are not equally susceptible to the erosion (Nikam et al. 2014). Therefore, it is necessary to identify a critical watershed in order to be treated on the priority basic. In this way, without enormous hydrological information, morphometric parameters alongside satellite based land cover data of watershed might be helpful in prioritizing the sub watersheds.

Morphometric analysis of a drainage basin can be achieved through the use of modern technologies such as Geographical Information Systems (GIS) whereas conventional measurements of morphometric parameters are laborious and cumbersome. The Digital Elevation Model (DEM) has been also proven to be efficient in extracting data for hydrological and water quality models (Martz and Garbrecht 1998; Smith and Vidmar 1994; Tarboton 1997; Wang and Hjlmfelt 1998; Lee 1998; Klingseisen et al. 2007; Mahmood et al. 2012; Gioti et al. 2013; Huang et al. 2013; Sen and Kahya 2017). In evaluating soil disintegration, a few observational models in view of geomorphological parameters were developed for measuring silt yield in the past (Jose and Das 1982; Garde and Kothari 1987; Mishra and Jain. Recent studies showed that remote sensing (RS) and GIS tools and techniques have high rates of efficiency and effectiveness for improvement and controlling of watershed and prioritization of sub-watersheds in soil and water management (Sahu et al. 2015; Farhan and Anaba 2016; Meshram and Sharma 2017). In the ongoing decades, numerous scientists have concentrated on Multi-Criteria Decision Making (MCDM) systems for tackling difficult decision-making problems. The MCDM based strategies in different fields of Human Resource Management (HRM) has been reported in various investigations (e.g., Borana et al. 2009; Petkovic et al. 2012; Güngör et al. 2009; Kilic and Cevikcan 2011; Kilincci and Onal 2011; Aher et al. 2013; Vivien et al. 2011). The application of MCDM methods in various fields has been considered by many researchers (Golfam et al. 2019; Razavi Toosi and Samani 2017; Liu et al. 2019; Ezbakhe and Perez-Foguet 2018; Asl-Rousta and Mousavi 2018; Meshram et al. 2019).

The primary aim of this study is to evaluate the applicability of morphometric parameters using SAW, TOPSIS, Borda and Copland models in order to prioritize sub-watersheds of Narmada basin, India in term of susceptibility to erosion. Soil erosion affects serious ecological issues similar to reducing soil production and filling basins by sedimentation in the Narmada basin. Our exploration will produce immense data, which can help water resource engineers in detailing more fruitful soil and future water preservation designs in the basin. In order to identify areas, which should be sensitive to erosion, the utilization of the MCDM system in modelling and morphometric parameters plays an important role to develop new methodologies to control the soil erosion with more proficient solutions (Mekonnen et al., 2015). However, the awareness of the aforementioned facts in the basin has yet been addressed and no such scientific assessments have been reported for a basin so far. Therefore, the outcomes of this study are novel and important to the concerned water resources authorities.

2 Materials and Methods

2.1 Study Area

Bamhani and Mohgaon watersheds are located in Mandala district of Madhya Pradesh, India and cover an area of 2542 km^2 and 3978 km^2 between latitudes $21^{0}65'55''$N and $22^{0}29'00''$N and longitudes $80^{0}22'00''$E and $81^{0}00'00''$E, respectively (Fig. 1). The elevation of measuring site at Mohgaon drops to 509 m. Climate dominating in the basin is classified as sub-tropical and sub-moist with annual average precipitation of 1178–1547 mm. The watershed zone consists of both flat and undulating lands with forest land and cultivated lands. Soil types mostly are red and yellow silty topsoil, and silty clay. Forest and agricultural lands share around 53% and 12% of the watershed zone, respectively (Gajbhiye et al., 2013a, b).

2.2 Prioritization and Mapping

For the digitization of watershed boundary, sub-watershed boundary and stream network were prepared in a GIS environment. Delineation of sub-watersheds of the Bamhani and Mohgaon

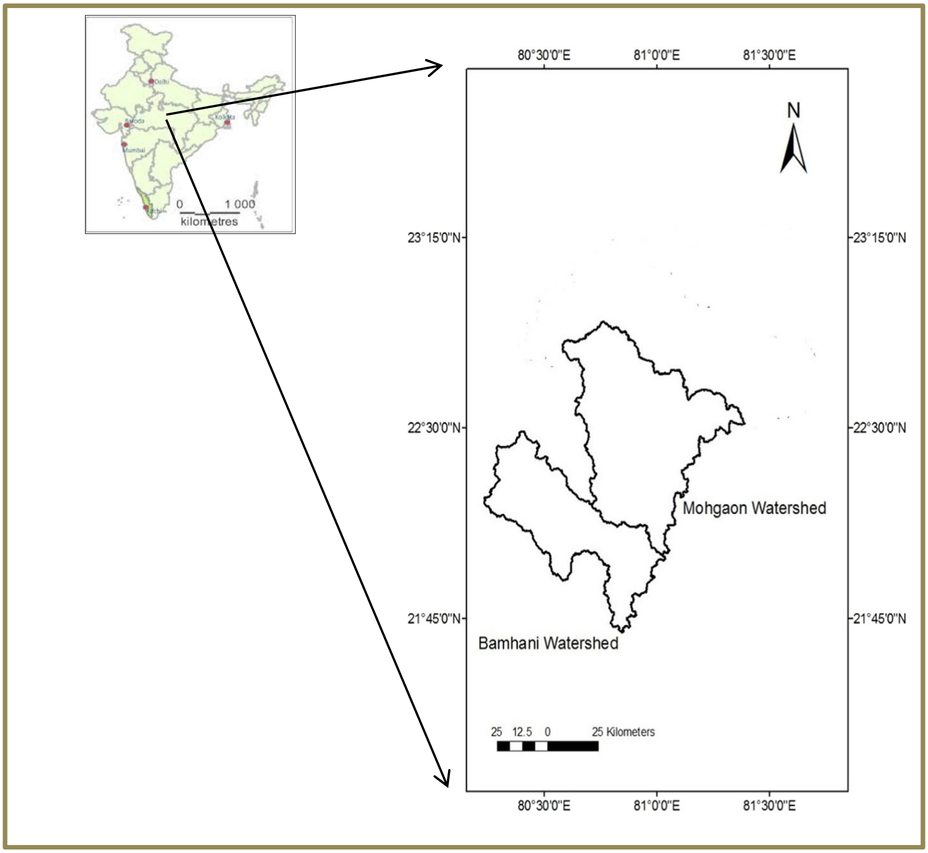

Fig. 1 Location map of the study area

watersheds and preparation of respective drainage map were made through the use of DEM, which was generated from SRTM dataset. These sub-watersheds boundary and drainage network were used for further geomorphological analysis. The morphometric parameters computed using a GIS system contains area, perimeter, stream order, stream length, stream number and elevation, which were obtained from the digitized coverage of the drainage network map. However, other parameters calculated by formulas given in Table 1 were used to compute the morphological parameters in our sub-watersheds.

In this study, we carried out watershed prioritization starting with the calculation of the morphometric parameters in each sub-watershed. Later we compared the results of those indicators to place sub-watersheds in order using the SAW and TOPSIS methods. It is worthwhile to emphasize that a total of 14 morphometric parameters were taken into consideration in our sub-watershed prioritization.

2.3 Multi-Criteria Decision Making (MCDM) Techniques

In this section, we presented an outline of the two MCDM methods adopted in this study (namely, TOPSIS and SAW).

2.3.1 SAW (Simple Additive Weighting)

The SAW is known as weighted direct mix technique. In this method, alternative scores are determined by the following equation (Sargaonkar et al., 2010).

$$r_{ij} = \frac{r_{ij} - Min\left(R_{ij}\right)}{Max\left(r_{ij}\right) - Min\left(r_{ij}\right)}$$

$$A^* = \left\{A_i | \max \sum_{j=i}^{n} w_j r_{ij}\right\} \tag{1}$$

Where W_j: weight assigned to each of the indicators, A^*: the most suitable option, r_{ij}: normalized weight (j^{th} criterion), and m: criteria number.

2.3.2 TOPSIS

The TOPSIS, which was first presented by Hwang and Yoon (1981), is one of the separation based techniques. The focal standard in TOPSIS display is that the best alternative ought to have the shortest partition from the ideal course of action as opposed to the most remote division from the negative- idealize arrangement. Since the input data to be used in TOPSIS are not scaled, the criteria values were here standardized using the following relation (Hwang and Yoon, 1981).

$$n_{ij} = \frac{r_{ij}}{\left(\sum_{i=1}^{m} r_{ij}^2\right)^{\frac{1}{2}}} \tag{2}$$

As indicated earlier, the best option would be the one that is closest to the positive-perfect arrangement and most remote from the negative perfect arrangement. To this end, we first determined the positive and negative ideal solutions using Eqs. 3 and 4.

Table 1 Formula 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	Schumn (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)	Schumn (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., (1991)
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 A = Watershed area	Nautiyal (1994)
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)

Table 2 Morphometric parameters of the study watershed

Sub- watershed	Rh	Rr	RN	Rb	Dd	Fs	Rc	Rf	Re	T	Lo	Cc	Sa	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
MG 1	0.037	0.009	0.961	3.339	2.418	6.277	0.551	0.700	0.944	9.382	0.207	0.032	9.523	0.393
MG 2	0.016	0.004	1.298	5.019	3.091	7.854	0.435	0.584	0.863	28.542	0.162	0.008	13.253	0.413
MG 3	0.024	0.006	0.924	4.147	2.888	7.692	0.379	0.569	0.852	13.195	0.173	0.022	12.108	0.393
MG 4	0.023	0.005	1.014	3.869	3.170	8.058	0.483	0.702	0.946	18.324	0.158	0.016	9.797	0.500
MG 5	0.010	0.002	1.044	5.558	2.269	7.892	0.219	0.310	0.628	26.127	0.220	0.006	10.532	0.420
MG 6	0.011	0.003	1.107	4.234	2.914	7.835	0.362	0.332	0.650	27.554	0.172	0.007	11.843	0.500
MG 7	0.014	0.003	1.109	4.407	3.082	7.388	0.227	0.287	0.605	13.776	0.162	0.015	10.033	0.500
MG 8	0.010	0.002	1.276	3.951	3.357	8.016	0.268	0.376	0.692	26.151	0.149	0.007	7.558	0.557
MG 9	0.016	0.005	1.028	3.907	2.942	7.671	0.476	0.348	0.665	18.205	0.170	0.015	9.132	0.551
MG 10	0.034	0.008	0.909	3.306	3.247	7.623	0.484	0.720	0.958	10.376	0.154	0.035	6.461	0.561
MG 11	0.016	0.002	1.117	4.140	3.102	7.758	0.160	0.658	0.916	15.943	0.161	0.011	9.101	0.500
MG 12	0.015	0.005	0.849	3.759	3.144	7.637	0.462	0.356	0.674	15.095	0.159	0.019	9.586	0.375
MG 13	0.013	0.003	0.875	4.375	2.918	7.929	0.299	0.470	0.773	18.820	0.171	0.012	4.303	0.500
MG 14	0.012	0.003	0.980	4.624	3.266	8.053	0.353	0.563	0.847	24.382	0.153	0.009	9.002	0.443
MG 15	0.008	0.002	0.936	4.904	3.119	7.633	0.227	0.250	0.564	18.687	0.160	0.010	10.100	0.443

BM Bamhani, *MG* Mohgaon

Table 3 Priority ranking of the sub-basins (Mohgaon watershed)

Sub basin name	Score based on SAW	Prioritization ranks based on SAW	Score based on TOPSIS	Prioritization ranks based on TOPSIS
MG1	0.85147	15	0.832	15
MG2	0.35817	6	0.326	7
MG3	0.58821	13	0.561	13
MG4	0.55164	12	0.521	12
MG5	0.23979	1	0.167	1
MG6	0.28207	3	0.213	2
MG7	0.34647	5	0.307	5
MG8	0.25296	2	0.229	4
MG9	0.42327	8	0.412	10
MG10	0.74505	14	0.827	14
MG11	0.42707	9	0.343	8
MG12	0.54265	11	0.458	11
MG13	0.45322	10	0.362	9
MG14	0.41012	7	0.31	6
MG15	0.30067	4	0.22	3

$$A^{+} = \left\{ \left(\max v_{ij} | j \in J_1 \right), \left(\min v_{ij} | j \in J_2 \right) | i = 1, 2, m \right\} \tag{3}$$

$$A^{-} = \left\{ \left(\max v_{ij} | j \in J_1 \right), \left(\min v_{ij} | j \in J_2 \right) | i = 1, 2, m \right\} \tag{4}$$

Where $A_i^{+} = \left(v_1^{+}, v_2^{+}, \ldots v_n^{+} \right); A_i^{-} = \left(v_1^{-}, v_2^{-}, \ldots v_n^{-} \right)$

$J1$={1,2,...,n|is associated with the positive criteria}

$J2$={1,2,...,n|is associated with the negative criteria}

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

Sub basin name	Score based on SAW	Prioritization ranks based on SAW	Score based on TOPSIS	Prioritization ranks based on TOPSIS
BM1	0.45492	10	0.415	9
BM2	0.79775	20	0.624	17
BM3	0.65798	17	0.66	19
BM4	0.3762	4	0.351	5
BM5	0.53811	13	0.502	14
BM6	0.37838	5	0.313	3
BM7	0.51974	11	0.441	10
BM8	0.63325	16	0.595	16
BM9	0.76486	19	0.727	20
BM10	0.43506	9	0.456	12
BM11	0.23931	1	0.196	1
BM12	0.5283	12	0.472	13
BM13	0.43069	7	0.386	7
BM14	0.67698	18	0.632	18
BM15	0.31447	3	0.293	2
BM16	0.42741	6	0.382	6
BM17	0.43189	8	0.402	8
BM18	0.60206	15	0.447	11
BM19	0.56242	14	0.558	15
BM20	0.29351	2	0.326	4

In the subsequent stage, the calculation of partition measures utilizing the n-dimensional Euclidean separation is required. The division of every option from the positive and negative perfect arrangement (d_i^+, d_i^-) is given as:

$$d_i^+ = \left\{ \sum_{j=1}^{n} \left(v_{ij} - v_j^+ \right)^2 \right\} \frac{1}{2}, (i = 1, 2, \ldots, m) \tag{5}$$

$$d_i^- = \left\{ \sum_{j=1}^{n} \left(v_{ij} - v_j^1 \right)^2 \right\} \frac{1}{2}, (i = 1, 2, \ldots, m) \tag{6}$$

Final step in the TOPSIS procedure is to calculate the relative intimacy to the perfect result and rank the performance order.

$$C_i = \frac{d_i^-}{\left(d_i^- + d_i^+ \right)}, (i = 1, 2, \ldots, m) \tag{7}$$

Since $d_i^- \geq 0$ and $d_i^+ \geq 0$, then clearly $C_i \in [0,1]$. The greater the index value, the improved the performance of the substitutes.

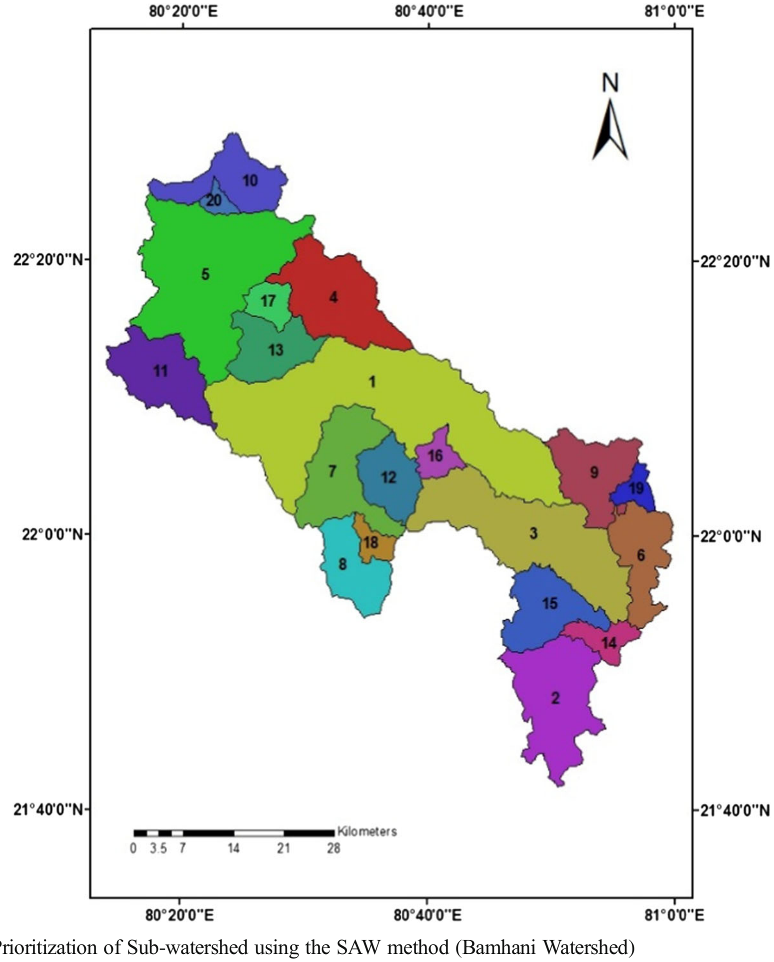

Fig. 2 Prioritization of Sub-watershed using the SAW method (Bamhani Watershed)

2.3.3 Aggregate Methods

This method is utilized to analyze the MCDM methods, which has two sequent stages (Wang et al., 2005). In Borda technique, each MCDM technique positions every one of the choices. In the event that there are k choices, every option gets k focuses for the main decision, k-1 focuses for the second decision, and so on. The option with the most focuses is noticed as the victor (Anisseh et al., 2009). In Copeland technique, which begins with the finish of Borda strategy, the first step is to compute quantities of misfortunes for the greater part of the choices. It decides the conspicuousness of any choices by subtracting quantities of loses from quantities of wins.

3 Results and Discussion

Morphometric parameters computed for each sub-watersheds are listed in Table 2. The description of notations is the same as those given in Table 1. Bamhani (Mohgaon) watershed is signified by BM (MG).

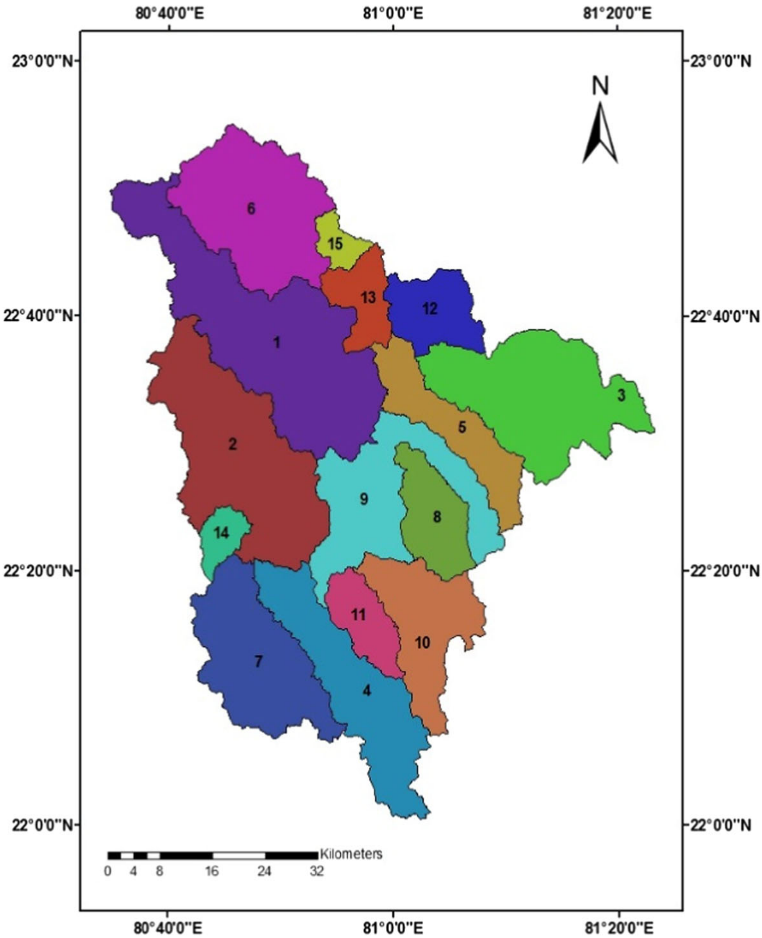

Fig. 3 Prioritization of Sub-watershed using the SAW method (Mohgaon Watershed)

3.1 Prioritization Using TOPSIS/ SAW Method

In the initial step, standardization of the data should be done prior to the development of choice matrix in executing multi-criteria decision making models. The criteria utilized as a part of this analysis have different estimation units (e.g., hill slope, drainage density, stream frequency), which should be standardized to solve this issue. For this reason, the linear technique (Eq. 2) was utilized in the TOPSIS model by the vector technique in this analysis. The next step was done to decide the weight of the criteria. After this, we calculated the weighted standardized decision matrix for the two MCDM models. The final weights of each sub-watershed using SAW were computed using entire weighted standardized matrix rows based on Eq.1 (Tables 3 and 4). The results of SAW model demonstrated that sub-watersheds MG-5, MG-8, MG-6 and BM-11, BM-20, BM-15 with the highest scores (corresponding numerical values: 0.239, 0.252, 0.282 and 0.239, 0.293, 0.314) are ranked 1 to 3 and thought to be utmost prone to erosion. In contrast, the sub-watersheds MG-1, MG-10, MG-3 and BM-2, BM-9, BM-14 with the relevant scores of 0.851, 0.745, 0.588 and 0.797, 0.764, 0.676 were noted in the last ranks, indicating the least sensitivity to erosion (Figs. 2 and 3).

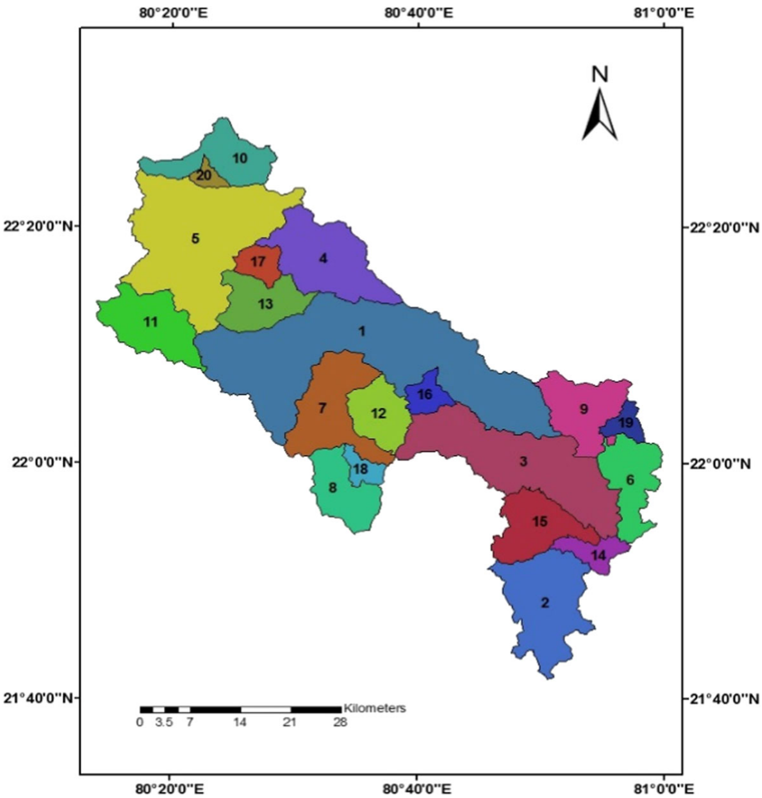

Fig. 4 Prioritization of Sub-watershed using the TOPSIS method (Bamhani Watershed)

The TOPSIS model revealed that the two groups of sub-watersheds MG-5, MG-6, MG-15 and BM-11, BM-15, BM-6 having highest corresponding scores (numerically 0.167, 0.213, 0.220 and 0.196, 0.293, 0.313) were found to match rank 1 to 3, indicating most vulnerable land parts to erosion. Furthermore, another two groups of the sub-watersheds MG-1, MG-10, MG-3 and BM-9, BM-3, BM-14 having lowest ranks with corresponding scores of 0.832, 0.827, 0.561 and 0.727, 0.660, 0.632 appeared to be least sensitivity to erosion (Tables 3 and 4**)** (Figs. 4 and 5). After ranking the sub-watersheds in terms of loss of natural assets, we categorized our study area into four classifications including very high (0–0.25); high (0.25–0.50); medium (0.50–0.75); and low (0.75–1). According to the SAW and TOPSIS models, sub-watersheds are classified into four classes as very high, high, moderate and low except Bamhani watershed, which indicated only three classes (i.e. moderate, high and very high) for the TOPSIS model (Table 7 and Figs. 6 and 7). Soil conservation measures should therefore be implemented through scientifically developed catchment areas immediately in erosion prone areas. It is also beneficial for agro forestry, grassland and reforestation to use scrub and open forests in the region studied. The agricultural land should be protected according to the suitability for slope, drainage and other requirements by agronomical measures such as contour

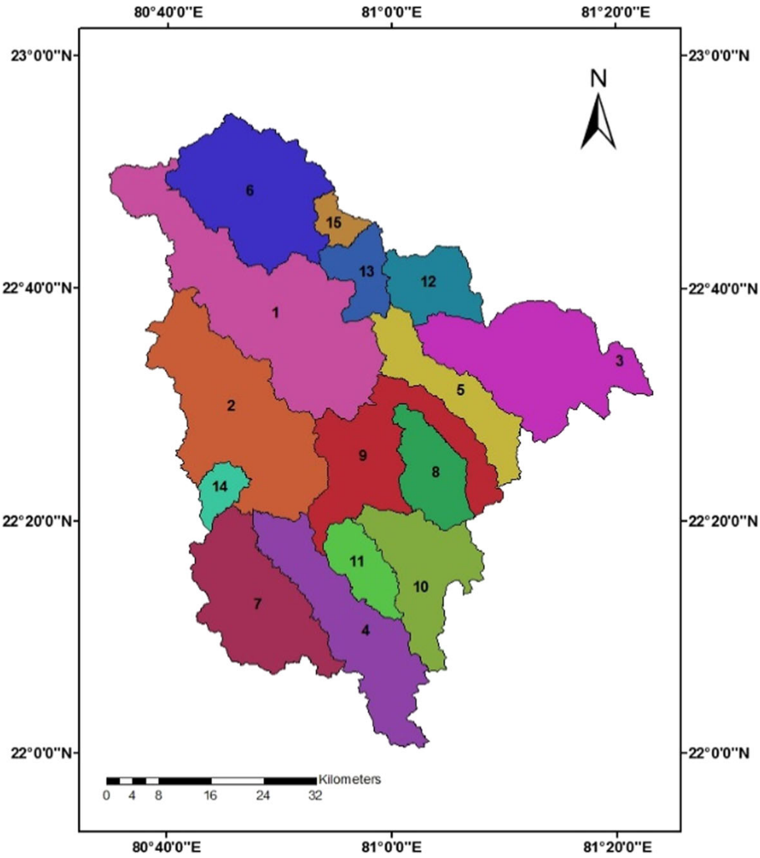

Fig. 5 Prioritization of Sub-watershed using the TOPSIS method (Mohgaon Watershed)

cropping, strip cropping, bench terracing and farm pond, and so on. It may be situated on a large population at high altitudes.

3.2 Prioritization Using Borda and Copland Method

The Borda and Copland techniques are one of the best approaches to compare prioritization processes between similar entities such as watershed. Because of this reality, it has been widely utilized by numerous specialists for the examinations concerning feasible planning and managing of sub-watersheds in provinces of data inadequacy (Altaf et al., 2014). A sub-watershed with a lowest value is positioned to the first place in terms of priority as having potential to highest erosion. The outcomes of prioritizing of the sub-watersheds by the Borda and Copland methods are presented in Tables 5 and 6. The analysis results showed that the two groups of sub-watersheds MG-5, MG-15, MG-6 and BM-11, BM-20, BM-15 were noted to correspond to the ranks 1 to 3, whereas another two groups of the sub-watersheds MG-1, MG-10, MG-3 and BM-9, BM-14, BM-2 took place in the last respective ranks. The consequences of prioritization of the sub-watersheds by the Borda and Copland strategies are presented in Tables 5 and 6. Our outcomes showed that the sub-watersheds MG-5, MG-15, MG-6 and BM-11, BM-20, BM-15 related to the respective ranks 1 to 3 (Figs. 8 and 9).

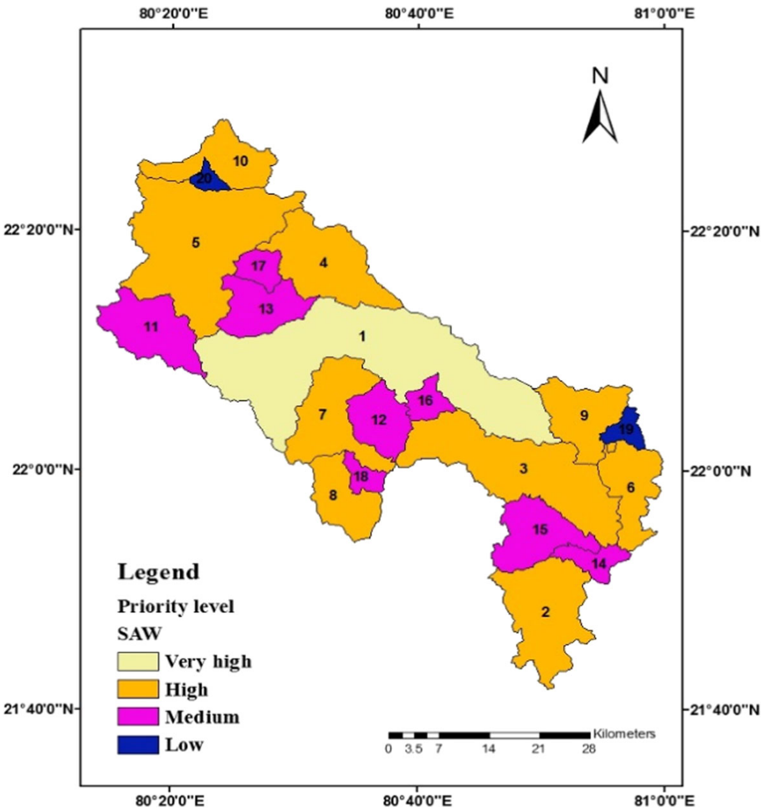

Fig. 6 Classification of sub-watershed to erodibility using SAW model (Bamhani Watershed)

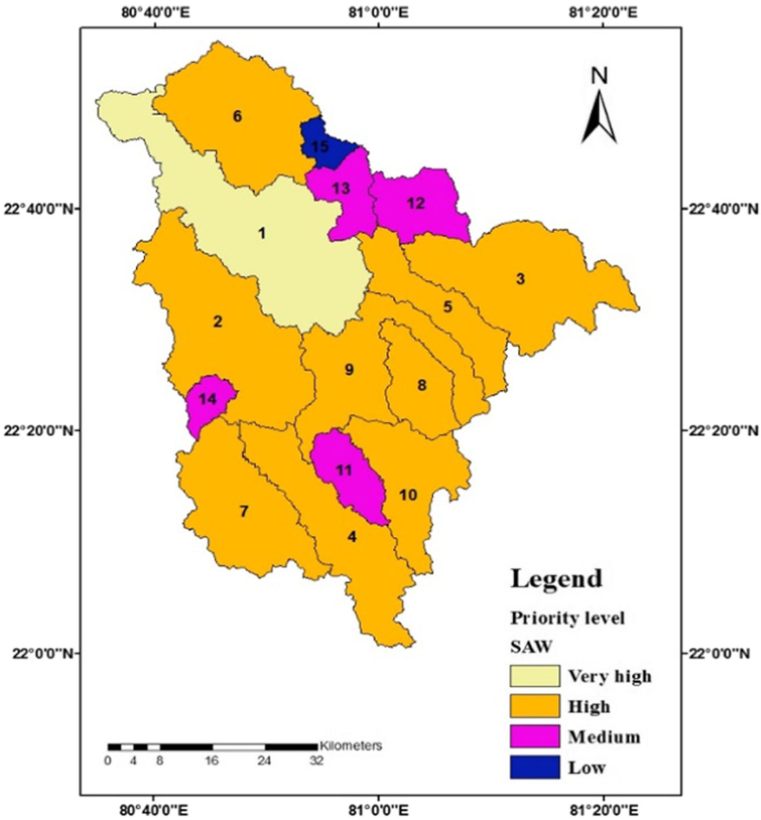

Fig. 7 Classification of sub-watershed to erodibility using SAW model (Mohgaon Watershed)

3.3 Planning for Soil and Water Conservation Measures

Soil and water conservation measures, structure numbers and different type structures have been presented for different sub-watersheds in this study. Decision makers will be able to compute the benefits of the project before implementation of above mentioned measures. Watershed treatment cannot be carried out on the basis of sub-watersheds without prior knowledge. The results of this study can provide guidance for water resources managers and planners in deciding treatment intensity and type in various sub-watersheds of the Narmada basin. It is possible to conclude that mechanical measures can be carried out at appropriate location, such as the bench terraces, contour trenching, contours bundings, gully plugs, brush

Table 5 Combining the rank of proposed techniques using Borda and Copeland methods (Mohgaon Watershed)

Priority	1	2	3	4	5	6	7	8
Borda Method	MG5	MG15	MG6	MG8	MG2	MG14	MG7	MG11
Copeland Method	MG5	MG15	MG6	MG8	MG2	MG14	MG7	MG11
Priority	9	10	11	12	13	14	15	
Borda Method	MG9	MG4	MG13	MG12	MG3	MG10	MG1	
Copeland Method	MG9	MG4	MG13	MG12	MG3	MG10	MG1	

Table 6 Combining the rank of proposed techniques using Borda and Copeland methods (Bamhani Watershed)

Priority	1	2	3	4		5	6	7	8	9
Borda Method	BM11	BM20	BM15	BM4, BM6		BM17	BM16	BM13	BM10	BM1
Copeland Method	BM11	BM20	BM15	BM4, BM6		BM17	BM16	BM13	BM10	BM1
Priority	10	11	12	13	14	15	16	17	18	19
Borda Method	BM7	BM18	BM12	BM19	BM5	BM8	BM3	BM2	BM14	BM9
Copeland Method	BM7	BM18	BM12	BM19	BM5	BM8	BM3	BM2	BM14	BM9

wood check dam, gabion check dam, percolation tanks and bunds. Sub-watersheds with medium priority can at a later stage be considered for mechanical treatment, whereas agronomic conservation measures with participatory management and awareness development among farmers in all sub-watersheds should be promoted (Table 7).

4 Conclusion

The present study indicated that the digital elevation model (DEM) with GIS system is an appropriate tool for sub-watershed delineation and extraction of its morphometric factors. In

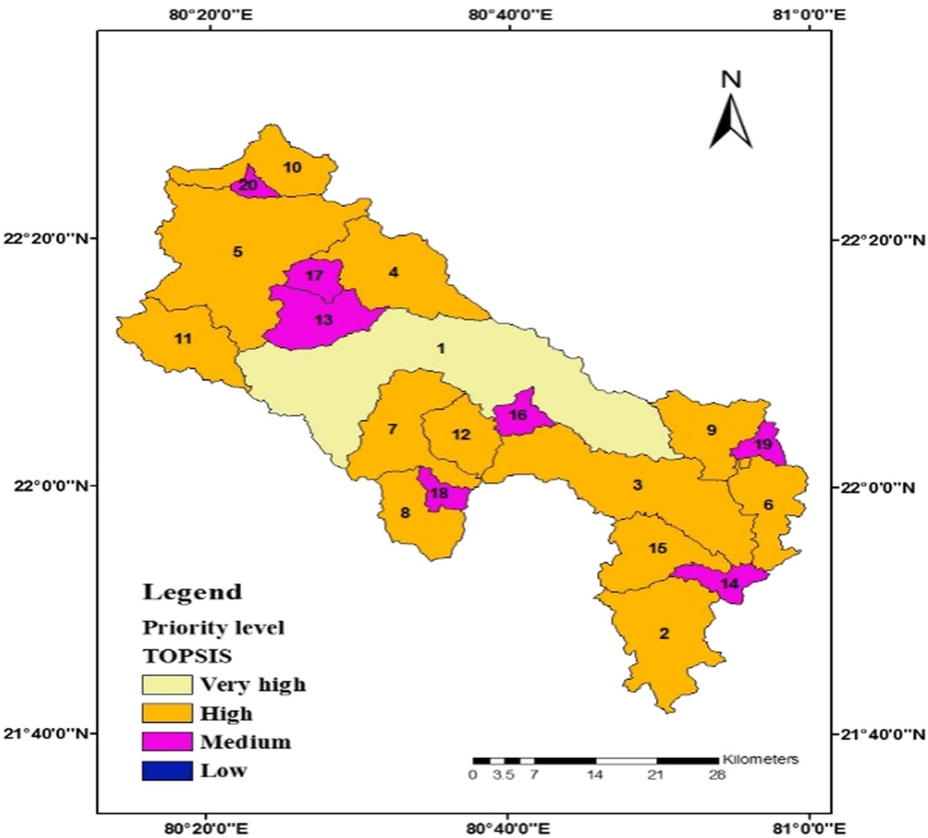

Fig. 8 Classification of sub-watershed to erodibility using TOPSIS model (Bamhani Watershed)

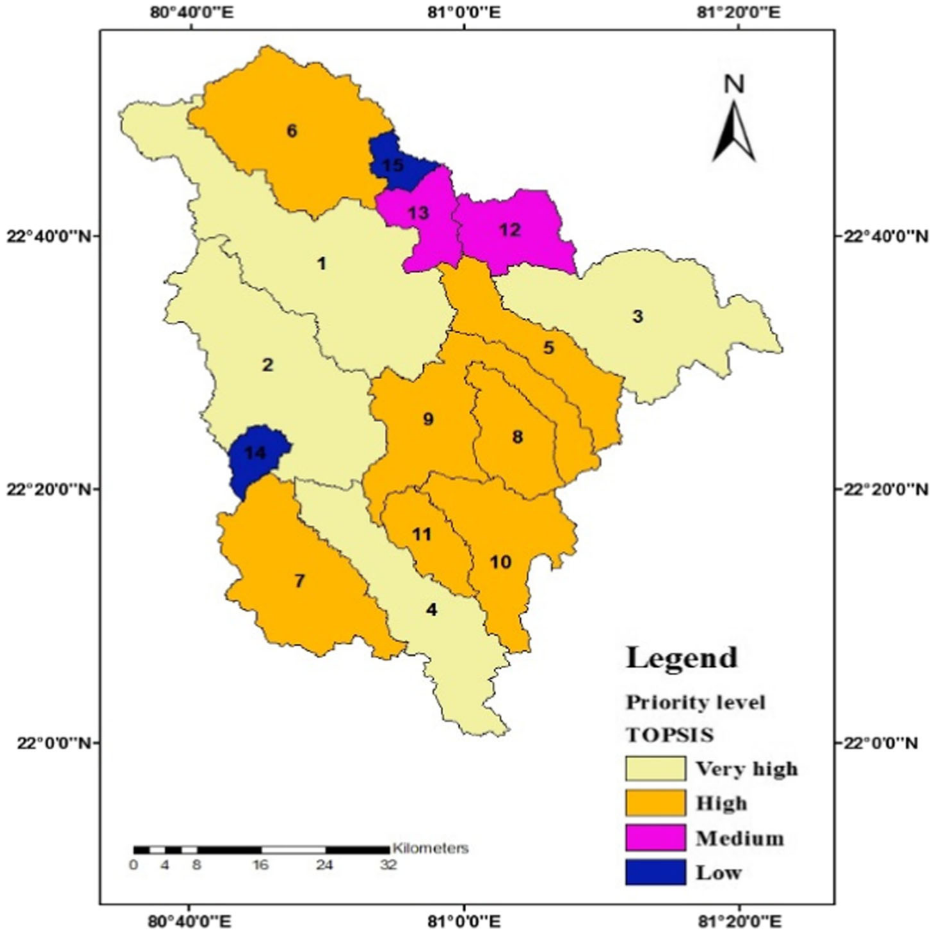

Fig. 9 Classification of sub-watershed to erodibility using TOPSIS model (Mohgaon Watershed)

overall, sub-watersheds in term of erosion in SAW and TOPSIS models were categorized into four classes including very high, high, moderate and low. The outcomes of SAW technique

Table 7 Priority level (Mohgaon and Bamhani watershed)

S. no.	Priority types	Priority levels	Sub-watersheds (SAW)	Sub-watersheds (TOPSIS)
1	Very High	0–0.25	MG5, BM11	MG5, MG6, MG8, MG15, BM11
2	High	0.25–0.50	MG2, MG6, MG8, MG7, MG9, MG11, MG13, MG14, MG15, BM1, BM4, BM6, BM10, BM13, BM15, BM16, BM17, BM20	MG2, MG7, MG9, MG11, MG12, MG13,MG14, BM1, BM4, BM6, BM7, BM10, BM12, BM13, BM15, BM16 BM17, BM18,BM20
3	Medium	0.50–0.75	MG3, MG4, MG10, MG12, BM3, BM5, BM7, BM8, BM12, BM14, BM18, BM19	MG3, MG4, BM2, BM3, BM5, BM8, BM9, BM14, BM19
4	Low	0.75–1	MG1, BM2, BM9	MG1, MG10

revealed that 165.68 km^2 (6.51%), 207.81 km^2 (5.22%) are situated in the very high erosion sensitivity class, 408.06 km^2 (16.05%), 814.39 km^2 (20.47%) in the high sensitivity class, 419.20 km^2 (16.49%), 1055.87 km^2 (26.54%) in the moderate sensitivity class, and 1459.06 km^2 (57.39%), 1899.93 km^2 (47.76%) in the low sensitivity class for the Bamhani and Mohgaon watersheds. The TOPSIS method showed that 104.20 km^2 (4.09%), 207.81 km^2 (5.22%) located in the very high erosion sensitivity class, 188.60 km^2 (7.41%), 242.34 km^2 (6.09%) in the high sensitivity class, 554.50 km^2 (21.81%), 1627.85 km^2 (40.92%) in the moderate sensitivity class, and 1694.70 km^2 (66.67%), 1899.93 km^2 (47.76%) in the low sensitivity class for the Bamhani and Mohgaon watershed.

Considering the high affectability of Narmada Basin in connection to erosion, it is strongly suggested that the essential protection methods should be taken to reduce soil erosion, to decrease sediment production in reservoirs, to stabilize steep slopes against landslide, and lastly to decrease future flood potential. Our study also demonstrated that GIS and RS methods in combination with MCDM approaches for example TOPSIS, SAW, Borda and Copland can be used by decision-makers and planners in the fields of soil and water resources in order to make suitable choices for control purposes. Prioritization of sub-watersheds might be perceived as a pragmatic technique that can be connected in the controlling of watersheds and the protection of water resources.

The results of this study could be benefited as guidelines for water resources managers and planners in fixing the intensity and type of treatments in different sub-watersheds of Narmada basin. It may be concluded that mechanical measures such as contour bund, brush wood check dam may be suggested on suitable location of very high and high priorities sub-watersheds where rate of soil erosion is high and slope is steep. The location of check dam and percolation tank may be suggested based on suitable location of medium and low priorities sub-watersheds.

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