



Pragmatic approach for prioritization of flood and sedimentation hazard potential of watersheds

Mohammad Reza Dahmardeh Ghaleno¹ · Sarita Gajbhiye Meshram^{2,3} · Ehsan Alvandi⁴

Published online: 4 April 2020

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Abstract

Flood is one of the natural disasters that generates a lot of damages every year in different points of the world. Also, soil erosion is among the processes that threatens the soil and water resources of the country. The performance of a small watershed is not same as the hydrologic response of a large watershed. Determining the amount of participation and prioritizing the sub-basins in terms of flood generation in the outlet of the basin can be a large help in correct locating the flood control and soil and water conservation projects and leads to decreasing the negative impacts of the flood control operations at unnecessary regions or at the regions with lower priority and also it prevents personal tastes. Therefore, determining the flood generator regions and prioritizing the sub-basins in terms of flooding and sedimentation potential is essential for better management of the watersheds. For this purpose, the aim of this research is to determine the amount of participation of the eastern sub-basins of the Gorganrud River Basin of Golestan province, Iran in flooding and sedimentation and their prioritization in terms of flooding and sedimentation potential using the multi-criteria decision-making methods. In this present study, we used area estimation indices, gravel coefficient, drainage density, basin average slope, basin average height, curve number, cover percentage, sediment yield, sediment delivery ratio, runoff height and concentration time. Indicators are considered to be important indicators affecting water permeability, runoff production and, consequently, the potential for flooding and sedimentation. Following the formation of decision matrix with 13 options (sub-basins) and 11 criteria (evaluation index), Technique For order Preference by Similarity to ideal Solution (TOPSIS), Simple Additive Weighting (SAW), Elimination Et Choice Translation Reality (ELECTRE) and Vise Kriterijumska Optimizacija Kompromisno Resenje (VIKOR) techniques were used to prioritize sub-basins. Borda and Copland methods were used to combine the rank of proposed techniques. Also, in order to validate the models, we estimated the percentage change and the intensity of the changes. The results showed that the highest runoff height index (0.179) and the average height index of the basin had the lowest weight (0.031), according to experts. Considering the results of the combined ranking of the proposed techniques, sub-basins 12, 1 and 2 are in first to third priority, respectively, and have a more critical situation than the rest of the sub-basins. Field studies clearly show the results of the research, because sub-basins 12 and 1 exhibit the highest erosion, poor soil and gradient. Also, zones with flood and sedimentation potential in the area showed that 49/31% of the area in high and very high risk. This study proves that multi-criteria decision-making methods and RS and GIS techniques are very suitable, precise, economically and temporally advantageous, and helpful tools to evaluate and prioritize the sub-basins in the soil erosion and soil and water conservation topics. Therefore, considering the multiple objective functions and the costly watershed management operations, it can be said that multi-criteria decision-making methods can be used for better management of watersheds in terms of biological and structural flood control operations. So, prioritization can be done based on a mathematical logic. The proposed method in this research is very suitable for watersheds without sufficient data. Hence, such researches which are low cost as well as quick can be used and watersheds can be prioritized for management and conservative acts.

Keywords Flooding · Sedimentation · Gorganrud basin · TOPSIS · SAW · ELECTRE · VIKOR methods

Communicated by V. Loia.

Extended author information available on the last page of the article

1 Introduction

Flooding and its catastrophic impacts have been unprecedented in recent times, especially with climate change and continuous changes in sea levels, is clearly of global importance (Nkwunonwo et al. 2015). It is worth noting that water erosion has many problems, such as declining fertility and soil productivity by reducing livelihoods, degrading ecosystems and spreading pollutants through the flow of sediment to rivers (Wang et al. 2003). The watershed is considered as a physical, social, economic, ecological and political unit for planning and management. Therefore, managers and policymakers should consider all dimensions of the system of watersheds in the planning of the catchment area (Sarangi et al. 2004). Since natural resource development projects are mainly implemented in catchment areas, their classification is necessary for the proper planning and management of natural resources for sustainable development (Jang et al. 2013). Prioritization of watersheds includes the classification of sub-basins based on the status of existing resources and the severity of erosion, which ultimately leads to corrective action and protection in sub-basins with high priority (Suresh et al. 2005).

One of the applications of multi-criteria decision-making methods is prioritization based on mathematical principles. Solving multi-criteria decision-making problems is complex, especially since most of the criteria are conflicting, increasing the utility of one can reduce other utility. For this reason, multi-criteria decision-making (MCDM) methods have been developed that help solve these problems (Zavadskas et al. 2014; Gao et al. 2018b; Alkaim and Al-Janabi 2020; Al-Janabi et al. 2020a, b, c). In the decision-making models of some compensatory indices, all indicators are considered for final decision making, and there is an exchange of indicators between them. This means that a change in an indicator is offset by a change in the index or other indicators (Zavadskas and Turskis 2011; Al-Janabi et al. 2015; Gao et al. 2018a; Al-Janabi and Alkaim 2019).

The application of multi-criteria decision-making methods in various fields has been considered by many researchers (Alvandi et al. 2017; Asl-Rousta and Mousavi 2018; Golfam et al. 2019; Liu et al. 2019; Meshram et al. 2020). Vivien et al. (2011) used the fuzzy MCDM method to select the best environmental schemes in the watershed, as well as Kaya and Kahraman (2011) using fuzzy VIKOR and AHP approaches to forest management decision making. Ahani Amineha et al. (2017) studied the integration of multi-dimensional spatial decision-making methods with Geographic Information System (GIS) in order to identify suitable areas for aquifer storage and retrieval. Gogate et al. (2017) studied the assessment of flood

management options in urban areas using multi-criteria decision-making method.

Prioritization of watershed basins has been considered by many researchers in various fields. Javed et al. (2009) prioritized sub-basins based on morphometric analysis and land use using remote sensing techniques and GIS in the Conway Basin. Aher et al. (2014) prioritized sub-basins to plan and manage the arid and semi-arid regions of India using a combination of remote sensing and GIS. Chandrashekara et al. (2015), using 24 morphometric parameters and geographic information system, compared the level of erosion and peak runoff in the two sub-basins of the Arkawati River Basin. Arami et al. (2017) studied the priority of watersheds in order to carry out management actions using the fuzzy hierarchy process analysis (FAHP). ArabAmeri et al. (2018) studied the priority of erosivity of sub-basins using morphometric parameters analysis and multi-criteria decision-making methods. Meshram et al. (2019) compared AHP and fuzzy AHP models for prioritization of watersheds.

In other studies, the socioeconomic aspects (Patil 2007; Gosain and Rao 2004; Newbold and Siikamäki 2009; Kanth and Hassan 2010), and land degradation as well as land use change are among the most effective factors for evaluation. The watershed landscape zones are (Deb and Talukda 2010; Kanth and Hassan 2010; Javed et al. 2011; Sarma and Saikia 2011; Gajbhiye et al. 2014; Gajbhiye and Sharma 2017; Ezbakhe and Perez-Foguet 2018; Gao et al. 2019; Al-Janabi et al. 2020a, b, c). One of the principles of carrying out any project, whether research or implementation in different fields, is prioritized. Also, in order to impose management or conservation measures in watersheds, it is important to prioritize sub-basins due to time and resources limitation (Foorootan et al. 2015; Gao et al. 2018c).

The eastern part of the Gorganrud basin has undergone extensive land use changes over the years, which has led to an increase in peak flood discharges and sediment production. Therefore, the study of flood and sedimentation of sub-basins in the eastern part of the Gorganrud Basin and its prioritization is important in order to reduce the risk of floods through conservation and management operations. To this end, the purpose of this research is to prioritize the potential of flooding and sedimentation in the eastern part of the Gorganrud basin, taking into account the compensatory MCDM models and mathematical science and optimization, so that the sub-basins can be used in different ways in terms of the flood and sedimentation potential was prioritized and the results were evaluated. Comparison of four multi-criteria decision-making methods of TOPSIS, SAW, ELECTRE and VIKOR in order to prioritize flooding and sedimentation potential of the sub-basins is one of the outstanding points of this research. The other

innovation of this research is that it considers more indicators and uses indicators such as land cover, curve number (CN), sedimentation, sediment delivery ratio, and time of concentration to prioritize the sub-basins in comparison with the same researches. In this way, planners and water managers can make appropriate decisions to solve the problems of this basin with the help of these prioritizations.

2 Study area

The eastern part of the Gorganrud Basin with an area of 224 thousand hectares and an average elevation of 564 m in the southeast of the Caspian Sea is located in the northern fold of Alborz. The basin is located at $55^{\circ} 16'$ and $56^{\circ} 4'$ east longitude, $37^{\circ} 19'$, $49^{\circ} 37'$ north latitude. The main cultivar of the study area is the agricultural land of hydroponics, rain forest, forest and pasture. The basin outlet at the Golestan dam is the lowest point in the altitude range of 44–79 m above sea level. Figure 1 shows the position of the study area.

3 Methodology

In this study, the priority of flood potential and sedimentation potential of sub-basins, the eastern part of the Gorganrud Basin of Golestan-Iran province, has been studied

according to the evaluation indicators and multi-criteria decision-making methods. The flowchart of the methodology is presented in Fig. 2. The study area was divided into 13 units of physiography according to the sensitivity of the region and the topographic condition from the digital elevation model (DEM) map in the ArcSWAT software environment. Further, at each of these 13 sub-basins, indicators such as area, gravel coefficient, drainage density, basin average slope, basin average height, curve number, cover percentage, sediment production, sediment delivery ratio, runoff height and time of concentration (T_c). The highest value of gravity coefficients, percentage vegetation cover and time of concentration was given a rating of 1, the next highest value was given a rating of 2 and so on as these indicators generally shows positive correlation with soil erosion. The lowest value was rated last in the series of numbers. The evaluation indicators are briefly presented in following text.

Area The watershed area reflects volume of water that can be generated from the rainfall. It is a necessary input in various hydrologic models.

Gravelius compactness coefficient The shape of the basin also has a significant effect on the flood hydrograph so that, with the constant of other physical conditions, the maximum flow of flood in the roundabouts is greater than that of the basins (Eq. 1).

$$C_c = 0.28 \times \left(\frac{P}{\sqrt{A}} \right) \quad (1)$$

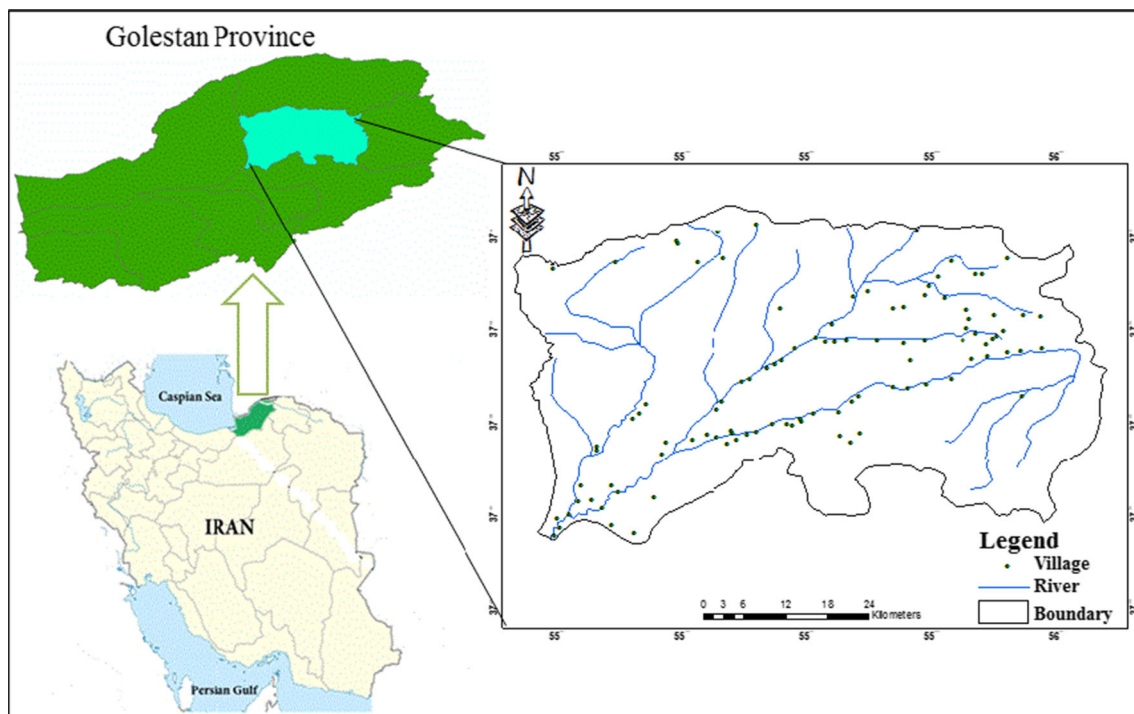


Fig. 1 Geographical location of the study area in Golestan, Iran

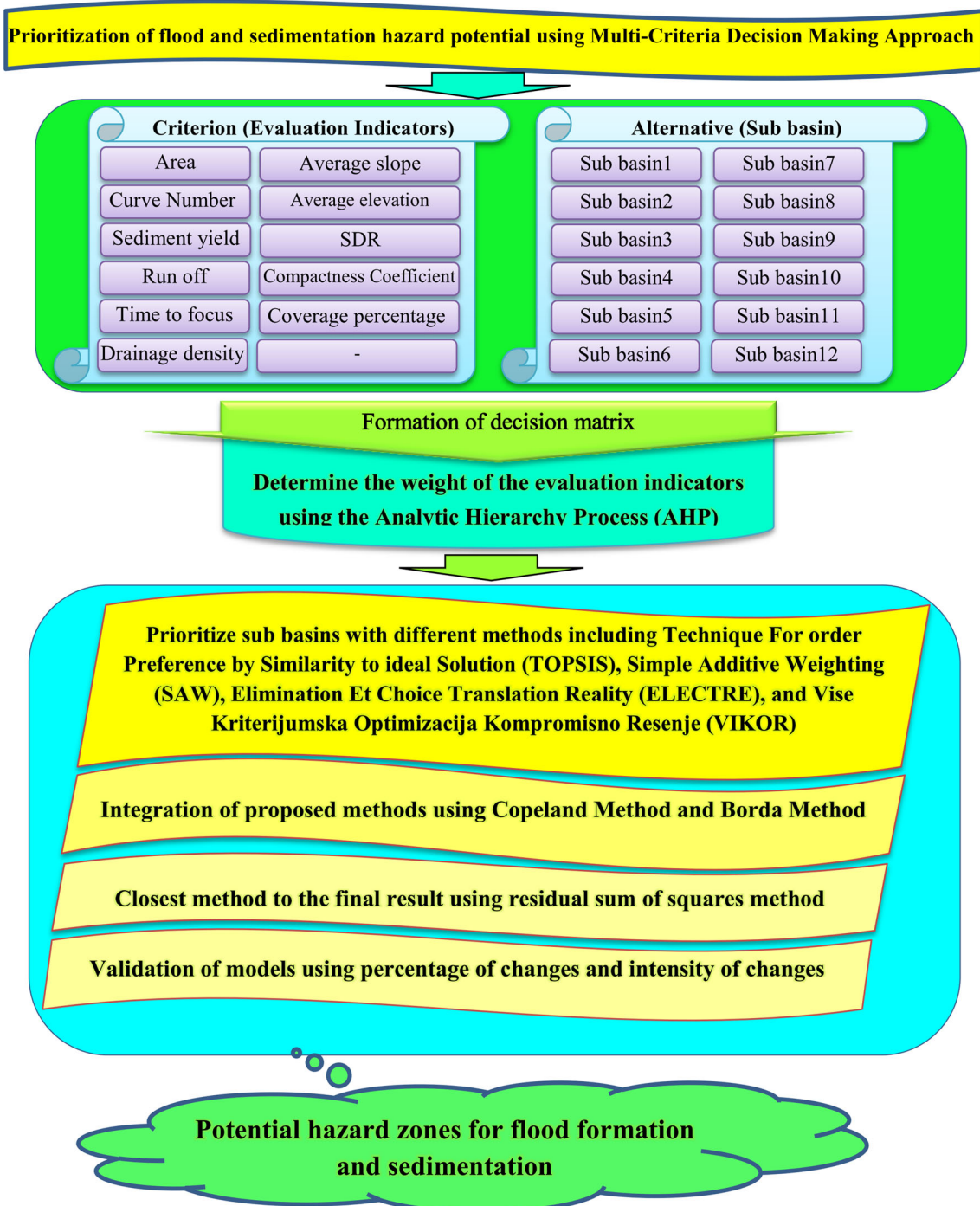


Fig. 2 Methodological framework of the study

where C_C : Gravelius compactness coefficient, P : perimeter of basin (km) and A : basin area (km^2) This coefficient is usually between 1 and 3.

Sub-basin average slope It plays a major role in runoff, penetration, flood intensity and erosion. At first, the gradient map of the studied area was prepared in ArcGIS environment and then the average slope of the 13 sub-

basins was calculated. The average elevation of the sub-basin has an important role in the amount and type of rainfall, evapotranspiration and vegetation status of the basin and consequently affects the runoff coefficient. The basin elevation map was extracted using ArcGIS software, and then the average elevation of each sub-basin was calculated.

Drainage density The total length of the hydrographic network, including rivers and canals, is obtained in the area of each sub-basin and is correlated with the maximum sub-basin fluxes. The total length of the hydrographic networks of the sub-basins of the study area was obtained using ArcGydo's software application in ArcGIS software.

Curve Number (CN) A dimensionless factor whose value varies from 0 to 100. In CN 0, runoff is not obtained from rainfall and in CN 100, all rainfall is flowing on the surface. In the present study, using a land use map and hydrologic soil groups map of the area, a basin curve number map was prepared under antecedent moisture condition (AMC II). Then, the CN weighted sub-basins were calculated.

Time of concentration The time is when water reaches the outlet from the farthest point of the basin. The concentration time is one of the important parameters affecting the flood waters of the basin. In this study, using the drill method, the time of concentration is estimated from the length of the main drainage channel and the main channel gradient.

Percentage vegetation cover Satellite images were used to extract coverage. Landsat satellite imagery for the 2012 region has been geo-referenced to ArcGIS software for land use planning. The normalized difference vegetation index (NDVI) was used to prepare land cover using Landsat satellite images. Then using the ILWIS software, land use was identified. In order to analyze vegetation cover percentages, the data field for each vegetation type was collected by stratified random sampling. In each quadrates, the percentage vegetation cover was estimated.

Estimated sediment production The Global Soil Loss Equation (RUSLE) model within the framework of the GIS was used to estimate the amount of soil erosion. The RUSLE factors include R, K, LS, C and P, which are calculated from rainfall data, regional soil maps, digital elevation models and remote sensing techniques, respectively.

In this study, using Eq. (2), the sediment delivery ratio was determined in each sub-basin and then, using Eq. (3), the sediment production value of each sub-basin was calculated.

$$SDR = 0.51 * A^{-0.11} \quad (2)$$

$$SY = SDR * SE \quad (3)$$

In which A is the area under the basin (km^2), SY is sediment yield (ton/ha/yr), SDR is sediment delivery ratio and SE is soil erosion (ton/ha/yr).

Subsequently, after determining and estimating the values of the evaluation indicators, priority was given to the flood potential and sedimentation of sub-basins using multi-criteria decision-making (MCDM) methods.

3.1 Determine the weight of the desired indexes

After estimating the value of each evaluation indices for 13 sub-basins, relative importance of each indicator is to be estimated. In this study, we use the AHP method to weigh each indicator. In this step, weighing the indices was extracted by referring to 10 experts in the corresponding weighting field for each of the indicators using the analytical hierarchy process (AHP) process. In the AHP method, the decision maker must compare each pair of decision-making criteria. Comparing the relative importance of each pair of criteria relative to each other is initially carried out qualitatively and then quantitatively on a numerical scale (1–9) (Opricovic and Tzeng 2004).

3.2 Unscaling the evaluation indicators

Input data are unmatched in MCDM techniques. So first, decision matrix D was formed with 13 options (sub-basins) and 11 criteria (evaluation indicators). In order to prepare the decision matrix D and comparable sub-basins, all indicators should be converted to a single scale. Therefore, in order to make the calculations and results meaningful, scientific methods were used to scale the data. For this purpose, in the SAW method, a soft linear method for data not scalarization (Eq. 4) has been used.

$$n_{ij} = \frac{r_{ij} - \text{Min}(r_{ij})}{\text{Max}(r_{ij}) - \text{Min}(r_{ij})} \quad (4)$$

In TOPSIS and ELECTRE methods, the Euclidean soft method is used to scale the data (Eq. 5).

$$n_{ij} = \frac{r_{ij}}{\left(\sum_{i=1}^m r_{ij}^2\right)^{\frac{1}{2}}} \quad (5)$$

In the VIKOR method, the fuzzy method is used to quantify the data, which is done in the computational formulas of the VIKOR method.

3.3 Prioritize sub-basins with different methods

After the data are not scaled, priority is given to the potential of flood and sedimentation of the sub-basins by the proposed methods. In the SAW method, one of the oldest methods used in MCDM, after determining the coefficient of significance of the indices and according to the decision less matrix, the coefficient of significance of each sub-basin is estimated using Eq. (6).

$$A^* = \left\{ A_i \mid \max \sum_{j=1}^n w_j r_{ij} \right\} \quad (6)$$

In this regard, w_j is the weight assigned to each of the indicators and A^* is the most appropriate option (sub-area).

The TOPSIS method is estimated using the weight of each scale-balanced scale matrix. This technique is based on the notion that the choice option should have the least distance with the ideal solution (best possible A_i^+) and the maximum distance with the ideal negative solution (the worst possible mode A_i^-). To this end, the ideal solution and the ideal solution are estimated using relations (7) and (8).

$$\begin{aligned} &\text{Ideal Positive Option } A^+ \\ &= \{(\max v_{ij} | j \in J_1), (\min v_{ij} | j \in J_2) | i = 1, 2, \dots, m\} \end{aligned} \tag{7}$$

$$\begin{aligned} &\text{Ideal negative option } A^- \\ &= \{(\min v_{ij} | j \in J_1), (\max v_{ij} | j \in J_2) | i = 1, 2, \dots, m\} \end{aligned} \tag{8}$$

$$A_i^+ = (v_1^+, v_2^+, \dots, v_n^+)$$

$$A_i^- = (v_1^-, v_2^-, \dots, v_n^-)$$

So that

$$\begin{aligned} J_1 &= \{1, 2, \dots, n | \text{For the positive elements of indicators}\} \\ J_2 &= \{1, 2, \dots, n | \text{For negative elements of indicators}\}. \end{aligned}$$

Then, the size of the distance is based on the Euclidean soft for the ideal negative solution and the positive and the same size is estimated for the ideal solution and the negative option is estimated using Eqs. (9) and (10).

$$d_i^+ = \left\{ \sum_{j=1}^n (v_{ij} - v_j^+)^2 \right\}^{\frac{1}{2}}, \quad (i = 1, 2, \dots, m) \tag{9}$$

$$d_i^- = \left\{ \sum_{j=1}^n (v_{ij} - v_j^-)^2 \right\}^{\frac{1}{2}}, \quad (i = 1, 2, \dots, m) \tag{10}$$

Finally, the relative proximity of the sub-basins is the ideal solution using the relationship of (11) and the sub-basins are prioritized according to their distance.

$$C_i = \frac{d_i^-}{(d_i^- + d_i^+)} \quad (i = 1, 2, \dots, m) \tag{11}$$

The ELECTRE method is one of the most important compensatory techniques. The application of this method is based on the concept of non-rank relationships. The answer obtained from this method is based on a set of ratings. In this method, we first obtain the weighted scalar matrix with respect to the weight values of the indices. Then, all options (sub-basins) are evaluated in pairs relative to all indices, and the harmonious and incoherent set is formed according to the relations (12) and (13).

$$\text{Harmonious collection} \begin{cases} S_{ki} = \{j | r_{kj} \geq r_{ij}\} \\ S_{ki} = \{j | r_{kj} \leq r_{ij}\} \end{cases} \tag{12}$$

$$\text{Inconsistent collection} \begin{cases} D_{ki} = \{j | r_{kj} < r_{ij}\} \\ D_{ki} = \{j | r_{kj} > r_{ij}\} \end{cases} \tag{13}$$

After creating a coherent and incoherent collection, we create a matrix of harmony and inconsistency. The matrix of coordination is a matrix of dimensions $m \times m$ and is estimated using Eq. (14). An inconsistency matrix is defined by NI, which is an $m \times m$ matrix and is estimated using Eq. (15).

$$J_{ki} = \sum w_j \tag{14}$$

$$NI_{ki} = \frac{j \in D_{ki}}{\text{MAX} | V_{ki} - V_{ij} |} \tag{15}$$

Then, to determine the effective coordination matrix and effective dissonance, the threshold is firstly estimated according to relations (16) and (17).

$$I = \frac{\sum_{i=1}^m \sum_{k=1}^m I_{k,i}}{m(m-1)} \tag{16}$$

$$NI = \frac{\sum_{i=1}^m \sum_{k=1}^m NI_{k,i}}{m(m-1)} \tag{17}$$

Finally, due to the general equation of (18), the matrix has been created.

$$F_{ki} = H_{ki} \times G_{ki} \tag{18}$$

The VIKOR method is an effective tool in multi-criteria decision making and is used to solve problems that are associated with incompatible and incompatible standards (Opricovic and Tzeng 2004). In this method, after forming the decision matrix, we determine the best and worst of the values available for each indicator in the decision matrix using Eqs. (19) and (20). In this way,

$$f_i^* = \max_j f_{ij} \quad \text{and} \quad f_i^- = \min_j f_{ij} \tag{19}$$

If the criterion is positive

$$f_i^* = \min_j f_{ij} \quad \text{and} \quad f_i^- = \max_j f_{ij} \tag{20}$$

If the benchmark is negative

where f_i^* are the best values and f_i^- are the worst values. In the next step, calculating the utility values of the group is the maximum of the majority (S) and individual loneliness at least from the opposite side (R) using Eqs. (21) and (22).

$$S_j = \sum_{i=1}^n w_i (f_i^* - f_{ij}) / (f_i^* - f_i^-) \tag{21}$$

$$R_j = \max_i [w_i (f_i^* - f_{ij}) / (f_i^* - f_{ij})] \tag{22}$$

In these relations, w_i is the index weight. Finally, the value of Q , which is a hybrid function and called the advantage function, is estimated using Eq. (23), which converges this function S and R into equations with weight. At the end of the sub-basin ranking and sub-basin selection.

$$Q_j = V(S_j + S^+) / (S^- - S^+) + (1 - V)(R_j - R^+) / (R^- - R^+) \quad (23)$$

where $S^+ = \text{Min}_j S_j$, $S^- = \text{Max}_j S_j$, $R^+ = \text{Min}_j R_j$ and $R^- = \text{Max}_j R_j$ is, and V is the weight determined by the maximum agreement of the group.

3.4 Integration of proposed methods

In this research, the technique of combining the rank of proposed techniques using the method of grafting and the method of Copland is used. To implement the Borda method, a non-diagonal matrix $m \times m$ is formed which describes the row to column in terms of the number of wires. If the number of boards in the techniques is higher, it is encoded with M and in that row is preferred to the column, and if the column is in line or the number of votes is equal, it is encoded with X . Finally, the total number of boards in each row is based on ranking. The higher the number of wins, the higher the rank in the copywriting method, not only the number of bets, but also the number of losses for each option (sub-area) is computed. In this way, the difference between the boards will be lost on the basis of ranking (Opricovic and Tzeng 2004).

3.5 Calculate Root Squared Error (RSS)

In order to obtain the closest method to the final result, we use the sum total squared error method (Eq. 24).

$$\text{RSS} = \sum_{i=1}^n (y_i - f(x_i))^2 \quad (24)$$

In this regard, y_i is the final rank and $f(x_i)$, the rank obtained by each of the multi-index decision-making methods.

3.6 Validation of models

In this study, to validate the models, we have estimated the percentage change and the intensity of the changes (Badri 2003).

Percentage change The percentage change in the ranking of each sub-area in each of the methods is estimated by the relationship of (25).

$$\Delta P = \frac{N - NN \text{ constant}}{N} \times 100 \quad (25)$$

In this regard, P = percentage change in the comparison of the two methods, N = total number of studied sub-basins, and NN constant = the number of sub-bases that are ranked in comparison with the two methods.

Severity of change The severity of the variations of the two methods in comparison with each other based on the

ranking of sub-basins in each method was calculated using formula (26).

$$\Delta I = \frac{\sum_{I=1}^N \frac{\text{rank}_{i(r1)}}{\text{rank}_{i(r2)}}}{N} \quad (26)$$

where I = the intensity of the variation of the two methods, Rank I (1) = the sub-basin I in the first method, Rank I (2) = the sub-baseline I in the second method and N = the number of sub-bases.

4 Results and discussion

The results of estimated indices in order to prioritize the flooding and sedimentation potential of sub-basins in the eastern part of the Gorganrud basin are presented in Table 1. The highest value of indicators, i.e., runoff, sediment delivery ratio, sediment yield, average elevation, average slope, drainage density among thirteen sub-basins was given rating of 1, the next highest value was given a rating of 2, and so on as these indicators generally show positive correlation with soil erosion. The lowest value was rated last in the series number. For the other indicators, i.e., percentage vegetation cover and Gravelius compactness coefficient, the lowest value was given a rating of 1, the next lowest value was given a rating of 2, and so on as these indicator generally shows negative correlation with soil erosion. According to the results of the evaluation indicators, the selection of critical sub-basins is difficult in these situations. Therefore, the necessity of using multi-criteria decision-making methods in prioritizing sub-basins seems necessary.

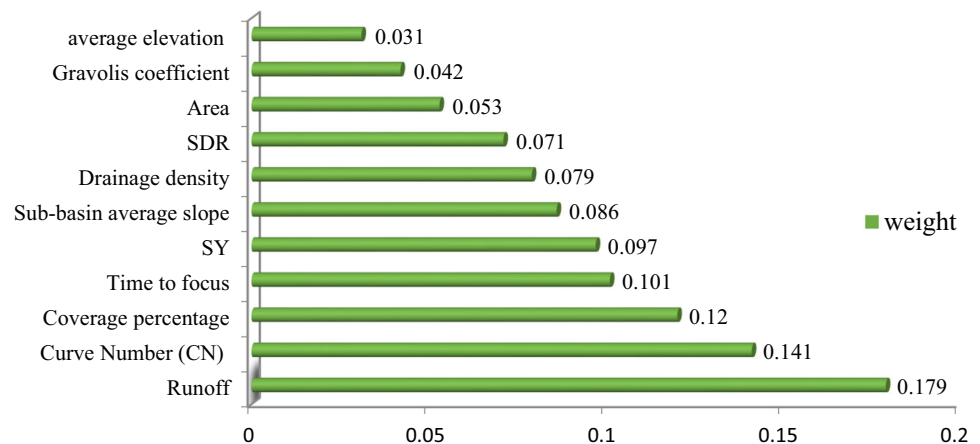
As mentioned above, the weighting of the AHP method is estimated for each of the indicators (Fig. 3). According to Fig. 3, the runoff indicator has the highest weight (0.179) and the average elevation of the basin has the lowest weight (0.031), (Gajbhiye et al. 2015; Arami et al. 2017). Therefore, it can be said that most of specialists believe that runoff height indicator has more influence on flooding and sedimentation potential. It should be noted that the adaptation rate (A.R.) indicates how much trust can be gained from the members of the group. Experience has shown that if the compatibility rate (C.R.) is less than 0.10, then comparative compatibility can be accepted; otherwise, comparisons should be made again. The results of the study showed that the compatibility rate (C.R.) is 0.03 and it is less than 0.10, so the compatibility of the comparisons can be accepted (Zavadskas and Turskis 2011).

The results of prioritizing the flood potential and sedimentation potential of sub-basins in the eastern part of Gorganrud Basin by using SAW, TOPSIS, VIKOR and ELECTRE methods are presented in Table 2. In the SAW

Table 1 Estimates of assessment indicators for prioritizing sub-basins in eastern part of Gorganrud basin

Sub-basin name	Area	Gravelius compactness coefficient	Drainage density	Average slope	Average elevation	Curve number (CN)	% Vegetation cover	SY	SDR	Runoff	Time to focus
SW1	309.08	1.608	1.07	11.76	731.35	82	14.2	1.99	0.271	12.17	0.651
SW2	123.44	1.512	0.98	9.02	481.24	80	10.65	3.87	0.300	9.78	0.600
SW3	146.32	1.296	1.02	8.47	445.39	74	11.76	2.55	0.294	5.14	0.602
SW4	161.94	1.518	0.99	4.5	379.03	75	12.08	1.36	0.291	5.72	0.688
SW5	128.38	1.630	0.99	14.18	663.09	79	18.32	0.19	0.298	9.48	0.578
SW6	117.97	1.933	1.11	7.82	434.25	76	13.29	2.12	0.301	6.78	0.674
SW7	239.02	1.340	1.06	8.83	1360	74	24.32	0.61	0.279	13.52	0.640
SW8	134.55	1.424	1.15	21.13	917.1	69	28.11	0.98	0.297	7.87	0.504
SW9	211.59	2.001	1.09	15.15	868.56	73	21.32	2.26	0.282	8.67	0.701
SW10	215.92	1.772	1.02	3.56	220.67	79	9.06	2.23	0.282	12.80	0.838
SW11	147.87	2.095	1.1	6.67	316.74	80	11.84	2.65	0.294	11.45	0.708
SW12	114.3	1.571	0.97	14	395.73	81	12.21	3.82	0.302	14.85	0.610
SW13	112.93	2.582	0.99	2.07	159.72	84	8.12	2.20	0.303	17.63	0.898

Bold values indicate highest and lowest value

Fig. 3 Estimated weight for each of the evaluation indicators using the AHP method

and TOPSIS method, the lowest score for the sub-basin has a higher priority in terms of corrective and protective measures and it is critical condition and the highest score has the lower priority. As shown in Table 3, the method of SAW, ELECTRE and VIKOR, sub-basin 12, 1 and 2 is ranked 1 to 3 and thought to be most susceptible to erosion, respectively, in the first to third allocated to have a more critical are the methods TOPSIS sub-basins 1, 12, and 9, respectively, have been assigned the first to third priorities, respectively. Finally, the results of TOPSIS model revealed that the sub-basin 1, 12 and 9 having the lowest respective scores (numerically 0.428, 0.449 and 0.468) is evaluated to match rank 1 to 3, implying most susceptible land pieces to erosion. Also, as Table 3 indicates, sub-basin 4 has located in the last order based on all methods of prioritization and has been introduced as the best sub-basin, because it has the least flooding and sedimentation potential.

The results of the prioritization of the 13 sub-basins of the eastern part of the Gorganrud basin using SAW, TOPSIS, VIKOR and ELECTRE methods are presented in order to compare the plot diagrams (Fig. 4). As you can see, for all of the multi-criteria decision-making methods, sub-areas 12 and 1 have the most flood and sediment and are in a more critical situation.

In this study, Borda and Copland methods were used to combine the rank of proposed techniques (SAW, TOPSIS, VIKOR, ELECTRE). The results of the combined ranking of proposed techniques using the Borda and Copland method are presented in Table 3, as it is clear that using the integration techniques, the sub-basin 12 is the first priority and has a more critical situation and the sub-basin 4 has the last priority. Therefore, the results of integrating the order of proposed techniques indicated that sub-basins 12, 1, and 2 have the highest flooding and sedimentation potential and

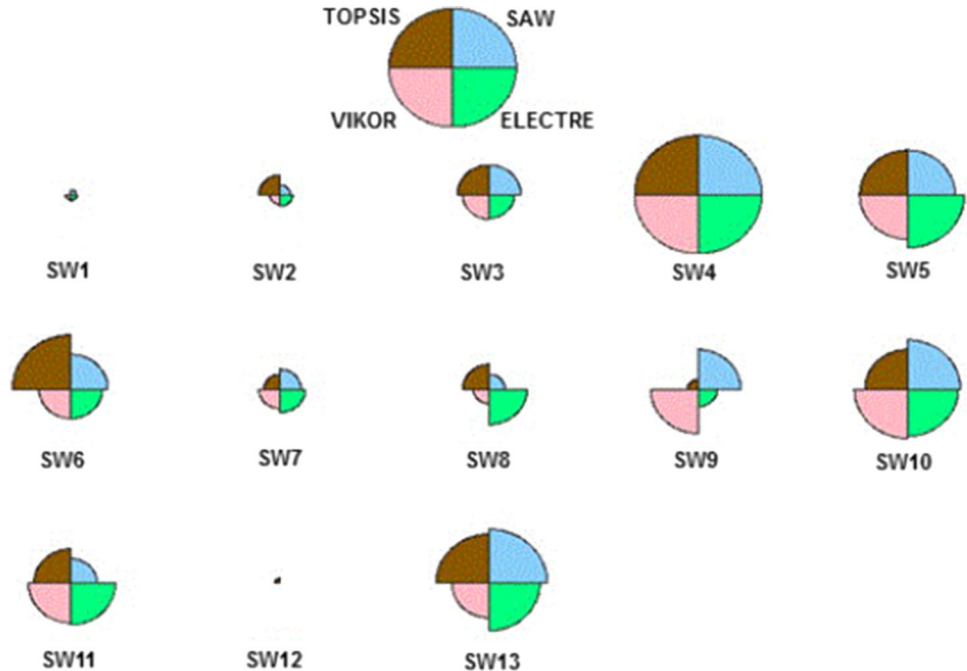
Table 2 Prioritization of sub-basins in the eastern part of the Gorganrud basin using multi-criteria decision-making methods

Sub-basin name	Score based on SAW	Prioritization ranks based on SAW	Score based on TOPSIS	Prioritization ranks based on TOPSIS	Score based on VIKOR	Prioritization ranks based on VIKOR	Prioritization ranks based on ELECTRE
SW1	0.404	2	0.428	1	0.968871	2	2
SW2	0.4349	3	0.49	5	0.903162	3	3
SW3	0.5179	7	0.568	7	0.716779	6	5
SW4	0.6153	13	0.665	13	0.199591	13	11
SW5	0.5287	10	0.593	10	0.477596	10	10
SW6	0.5241	8	0.627	12	0.629611	7	6
SW7	0.4856	5	0.475	4	0.792969	5	5
SW8	0.4641	4	0.5	6	0.83768	4	7
SW9	0.5264	9	0.468	3	0.224941	12	4
SW10	0.5601	11	0.593	9	0.476868	11	9
SW11	0.4933	6	0.589	8	0.550172	9	8
SW12	0.3885	1	0.449	2	0.97985	1	1
SW13	0.5759	12	0.612	11	0.587158	8	9

Table 3 Ranking of recommended techniques (SAW, TOPSIS, VIKOR, ELECTRE) using Borda and Copland methods

Priority	1	2	3	4	5	6	7	8	9	10	11
Borda method	SW12	SW1	SW2	SW7	SW8	SW3	SW9	SW11	SW6	SW5, SW10, SW13	SW4
Copland method	SW12	SW1	SW2	SW7	SW8	SW3	SW9	SW11	SW6	SW5, SW10, SW13	SW4

Fig. 4 Prioritization of sub-basins using four proposed methods (SAW, TOPSIS, VIKOR and ELECTRE)



should be given a high priority in the conservation and management acts. Also, sub-basin 4 with the least flooding and sedimentation potential has been introduced as the best sub-basin.

The root squared error (RSS) of the MCDM methods (SAW, TOPSIS, VIKOR, ELECTRE) is presented in Table 4. Among the four methods, SAW having a least RSS of 21 outperformed in terms of high efficiency and

Table 4 Calculating total squared error (RSS) proposed methods

Model	RSS
SAW model	21
TOPSIS model	39
VIKOR model	25
ELECTRE model	26

accuracy against the methods of TOPSIS, VIKOR and ELECTRE as their RSS was calculated as 39, 25 and 26, respectively (Table 4). Therefore, it can be said that the SAW method with the least total squares error has presented the best result in prioritizing the sub-basins in terms of flooding and sedimentation potential.

The percentage change of each method compared to each other is presented in Table 5. As it is seen (Table 5), the least percentage of change shown in SAW and VIKOR methods whereas the highest percentage of change shown in TOPSIS and ELECTRE methods. Among the four methods, the SAW method with the lowest percentage change was 44.23% in the first rank and TOPSIS method with the highest percentage change of 59.62% in the last rank. Therefore, it can be said that the SAW method with the least value of percentage change (44.23) has the best performance in prioritizing the sub-basins in terms of flooding and sedimentation potential (Arami et al. 2017; ArabAmeri et al. 2018).

The degree of variation of the two methods in comparison with each other, if equal to one, indicates the absence of changes. As far as number one is concerned, the intensity of the changes in the two methods is increasing in comparison with each other. In Table 6, the severity of variations of each method is presented by a pairwise comparison of the methods. The lowest change in the SAW method and the highest change in the ELECTRE method is observed. Therefore, it can be said that the SAW method with the least value of changes intensity (4.31) has the best performance in prioritizing the sub-basins in terms of flooding and sedimentation potential and the ELECTRE method with the highest value of changes intensity (4.52) had the worst performance in comparison with the other methods (Arami et al. 2017; ArabAmeri et al. 2018).

In addition, sub-basins were classified according to the estimated total weight in four classes: low, moderate, high and very high (Table 7). According to the above classification, it was found that 49.31% of the area is high and very high zone. About 50% of the region is in the critical state in terms of flooding and sedimentation and should be given the priority in conservation and management acts. Also, 28.62% of the region has been located in the low zone and has a suitable state. Finally, by mapping the map layers under the basins in the ArcGIS software environment and using the priorities of the integration methods (Borda and Copland), the zones with potential flood and

Table 5 The percentage of variations of the four suggested methods relative to each other

Method	SAW method	TOPSIS method	VIKOR method	ELECTRE method	Average of percentage of changes
SAW method	0	76.92	38.46	61.54	44.23
TOPSIS method	76.92	0	84.62	76.92	59.62
VIKOR method	38.46	84.62	0	61.54	46.15
ELECTRE method	61.54	76.92	61.54	0	50.00

Table 6 The severity of the changes in the four suggested methods compared to each other

Method	SAW method	TOPSIS method	VIKOR method	ELECTRE method	Total changes
SAW method	1	1.13	1.02	1.16	4.31
TOPSIS method	1.13	1	1.13	1.18	4.45
VIKOR method	1.02	1.13	1	1.18	4.33
ELECTRE method	1.16	1.18	1.18	1	4.52

Table 7 Risk of flood formation and sedimentation in the sub-basins of the eastern part of the Gorganrud Basin

S. no.	Priority types	Sub-watersheds	Percentage of area
1	Low	SW4, SW5, SW10, SW13	28.62
2	Medium	SW6, SW9, SW11	22.07
3	High	SW3, SW7, SW8	24.03
4	Very High	SW1, SW2, SW12	25.28

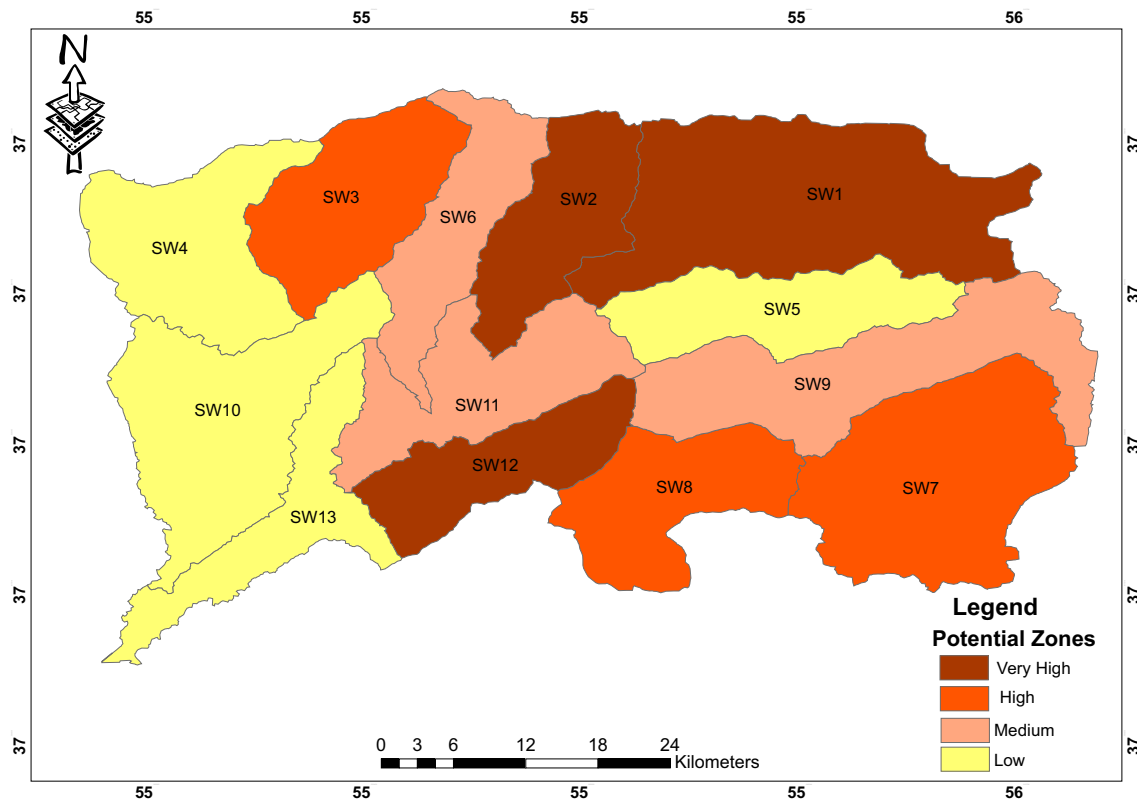


Fig. 5 Potential hazard zones for flood formation and sedimentation in sub-basins in the eastern part of the Gorganrud Basin

sedimentation of the sub-basins of the eastern part of the river basin Gorganrud are presented in Fig. 5. As Fig. 5 indicates, the sub-basins 12, 1 and 2 have been located in the very high zone in terms of flooding and sedimentation that it is about 25.28% of the region. Field studies clearly show the results of the research, because sub-basins 12 and 1 exhibit the highest erosion, poor soil and gradient.

5 Conclusion and future directions

In this research, multi-criteria decision-making methods were used to find the priority of flooding and sedimentation potential in eastern watersheds of the Gorganrud River Basin located in the Golestan province, Iran in order to erosion and flood control, and improving life of watershed residents socially and economically. Evaluation indices including area, Gravelius compactness coefficient, drainage density, average slope and elevation, curve number, percentage vegetation cover, sediment delivery ratio, sediment yield, runoff and time of concentration were used to prioritize the eastern sub-watersheds of Gorganrud River Basin. Weighting of the evaluation indices based on expert's ideas revealed that runoff and curve number (CN) indices have the highest weight and average elevation of

the watershed has the least weight. Hence, it can be said that the value of runoff and vegetation percentage are important and effective factors in flooding and sedimentation in the study area. In the other words, runoff has a considerable impact on prioritizing the watersheds due to its high and considerable weight, so that changes of this index create the most changes in sub-watersheds prioritization.

As results represent, some irregularities are observed in the selected priorities in all of the methods including ELECTRE, VIKOR, TOPSIS and SAW proposed to prioritize the sub-watersheds. By integrating the priority estimated by proposed methods, sub-watersheds 12, 1 and 2 are located in the first to third priority, respectively, and in very intense class in terms of flooding intensity and sediment generation. High slope, soil type and degradation of vegetation can be mentioned as the reasons for current situation. It should be mentioned that the sub-watershed 4 is located in the last priority, and hence, it has the least flooding and erosion. Therefore, critical sub-watersheds need to special attention in terms of improvement and conservation measures.

According to the RSS, SAW method has the least error and the most compatibility with the results of integrating the priorities of proposed methods and TOPSIS method has

the highest error and the least compatibility with the results of integrating the priorities of proposed methods. Exploring and analyzing the percentage of changes of the studied methods compared to the other results indicate that SAW and TOPSIS have the least and highest percentage of changes, respectively. Also, calculating the changes intensity for each of the methods indicates that SAW and ELECTRE are, respectively, located in the first (desired) and last (undesired) priorities in terms of this factor. In the resultant of the comparative analysis, it seems also that the SAW method has more reliability in the prioritizing the sub-watersheds comparing to the other methods because the percentage and intensity of the changes in the results of the SAW method are less than the others. Hence, the SAW method can be a suitable method for prioritizing the sub-watersheds.

Overall, it can be stated that about 50 percent of the study area is located in the high and very high flooding and sedimentation class and it is necessary to do the required actions based on the priority of the classes in order to control the flood and reduce the intensity of the flooding. Regarding the implementation of the biological and structural practices with some objective functions and considering the costly watershed operations, it can be said that multi-criteria decision-making methods can be used to prioritize based on a mathematical logic in order to manage the sub-watersheds.

Few number of the meteorological stations and lack of the synoptic stations are among the limitations of this research. Also, lack of a soil map of the region with high resolution had impact on the results of the simulation. Hence, uncertainty increases and the confidence to the results of the research decreases.

It should be noted that the value of P factor related to the soil conservation operations was considered as 1 for all of the regions due to the lack of sufficient information about this factor. Also, by default, the curve number map was prepared for the moderate antecedent soil moisture condition (case II).

This study proves that multi-criteria decision-making methods and RS and GIS techniques are very suitable, precise, economically and temporally advantageous, and helpful tools to evaluate and prioritize the sub-basins in the soil erosion and soil and water conservation topics. Therefore, multi-criteria decision-making methods and RS and GIS techniques for better management of watersheds are suggested.

Multi-criteria decision-making methods are practical and suitable approaches for better decision making based on the mathematics and optimization sciences. Therefore, considering the multiple objective functions and the costly watershed management operations, it can be said that multi-criteria decision-making methods can be used for

better management of watersheds in terms of biological and structural flood control operations. So, prioritization can be done based on a mathematical logic. The proposed method in this research is very suitable for watersheds without sufficient data. Hence, such researches which are low cost as well as quick can be used and watersheds can be prioritized for management and conservative acts.

Briefly, the method presented in this study has led to the structuring of decisions in the process of comprehensive assessment and management of watersheds. Therefore, future research on collaborative using multi-criteria decision-making methods with active role playing of all stakeholders is emphasized.

Therefore, it can be said that multi-criteria decision-making techniques are a practical and appropriate approach for better decision making based on mathematical sciences and optimization. Therefore, these types of low-cost and fast-track research can be prioritized to protect watersheds.

Acknowledgements The current research was funded by the research affairs of University of Zabol with the UOZ-GR-9618-85 Grant code.

Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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Affiliations

Mohammad Reza Dahmardeh Ghaleno¹ · Sarita Gajbhiye Meshram^{2,3} · Ehsan Alvandi⁴

✉ Mohammad Reza Dahmardeh Ghaleno
mr.dahmardeh@uoz.ac.ir

Sarita Gajbhiye Meshram
saritagmeshram@tdtu.edu.vn

Ehsan Alvandi
alvandi_u_2010@yahoo.com

² Department for Management of Science and Technology Development, Ton Duc Thang University, Ho Chi Minh City, Vietnam

³ Faculty of Environment and Labour Safety, Ton Duc Thang University, Ho Chi Minh City, Vietnam

⁴ Department of Watershed Management, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran

¹ Department of Range and Watershed Management, Faculty of Water and Soil, University of Zabol, Zabol, Iran