Non-compensatory decision model for incorporating the sustainable development criteria in flood risk management plans

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Abstract

It is necessary to incorporate Sustainable Development Goals into the selection of Flood Risk Management Plans (FRMPs). This paper is assessing the FRMPs by grouped Sustainable Development Criteria (SDC) criteria. The utilized Multi-Criteria Decision Making (MCDM) models to evaluate FRMPs were chosen from three groups of compensatory, Semi-non compensatory, and non-compensatory models. Sensitivity and uncertainty analysis of input data such as SDC's weights and Criteria' Weight Assessment (IWA) methods were used to compare the results in different groups of MCDMs, IWAs, and their constructions. The results showed that Step-wise Weight Assessment Ratio Analysis (SWARA) had reasonable results as IWA method, while Shannon's Entropy had not satisfied outcomes. The compensatory model was affected by changes in input data, while Semi-noncompensatory and noncompensatory models had more stable results. Based on the SWARA-PROMETHEE model the combination of designing the warning system and employing a flood insurance program was in the first rank, flood peak alleviation by Golestan-I reservoir is in the second rank, designing a warning system was in the third rank, building a diversion canal and levees in the study area were fourth and fifth rank, respectively. Employing a flood insurance program was in the last priority by SWARA-PROMETHEE model. The combination of SWARA-PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) model is recommended for the ranking of FRMPs because of the better incorporating SDC in flood management plan in comparison to other models, and demonstrating better results in IWA sensitivity analysis as well as Criteria' Weight (IW) uncertainty assessment.

Keywords Decision support · Flood mitigation · Flood management · Risk management · Sustainable development · Sustainability

1 Introduction

Floods can destroy infrastructures and can cause damages rivers and floodplains' environments [14, 17, 23, 42]. Vulnerability to flood disasters tends to increase globally with climate change [25]. While floods can jeopardize sustainable development, flood protection management should be part of sustainable development. Considering the influence of floods regarding sustainability planning is important for long-term hazard reduction [39]. Although

sustainable development is commonly used, there is a limited understanding towards application of this term. At a broader perspective, sustainable development (SD) includes three major objectives: being economically feasible, socially acceptable, and environmentally sound [29].

Evaluation of Flood Risk Management Plans (FRMPs) in a sustainability context can lower costs and reduce fewer impacts on social and environmental through better adaptation to the environment. The use of sustainable development criteria (SDC) to evaluate flood management is thus

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an ideal option. Since SDC have different values, qualitative or quantitative, comparison between each other is problematic [6, 20]. The consequence of floods on a society be contingent on the affected state's economic power prior to the flood [21]. To address this issue, Criteria'Weight Assessment (IWA) methods with different computational processes are used to evaluate SDC preferences. Analytic Hierarchy Process (AHP) method as one of the most wide spreads method in weight assessment, which is used to evaluate tangible and intangible criteria based on pairwise comparisons [13, 45]. Step-wise, Weight Assessment Ratio Analysis (SWARA) is another method for weighing decision attributes using expert opinion, while Shannon's Entropy method enable decision makers to obtain weights without privileged data or direct judgment of experts [31]. Use of common evaluation measures have difficulties and it becomes necessary to use multiple criteria decision making (MCDM) models for applying SDC in selection of best FRMPs.

Vlsekriterijumska Optimizacija I KOmpromisno Resenje (VIKOR) model is a compensatory MCDM model developed by Opricovic and Tzeng [41], which is intended to solve MCDM problems with conflicting objectives. The reason of choosing VIKOR model is its popularity in MCDM analysis and application of VIKOR method has upward trends in recent studies regarding MCDMs [35]. It is used extensively in water resources management to optimize decisions involving multiple objectives [50]. The integration of suitable scientific data is then essential to contribute in knowledgeable management [33, 50]. VIKOR model is applied to water resources management in the Mlava River [40]. This model is employed to define compromise solution to a decision issue with non-commensurable indices that represent Sustainable Development Goals (SDG). Chang and Hsu [10] used VIKOR model to determine the best feasible solution of land use limitations for Tsen-Wen watershed in southern Taiwan. These examples show the use of compensatory model, VIKOR, in water resources management.

The ranking of flood management projects could also be done through semi-non-compensatory MCDM modeling. ELimination and Et Choice Translating REality (ELECTRE I) model is an outranking (semi-noncompensatory) MCDM model that was developed by Roy [44]. It used extensively for solving selection problems due to the time saving analysis and being easy to use and understand. In this model, ranking of FRMPs is achieved by means of pairwise comparison. Dominance and non-dominance FRMPs are determined by a concordance and discordance matrix. In semi-noncompensatory model like ELECTRE I, positive high score of one criterion can compensate for negative low score of the other criterion, but not negative high score.

Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) has a non-compensatory rationality [7]. It is one of the most common ranking MCDM method and is suitable for sustainability assessments [24, 26]. This method is flexible model regarding quantitative input data and has appropriate performance in quantitative analysis in comparison other MCDM models [37]. The criteria' weights (IW) is linked to the grade of their comparative significance and it is in two phases: enriching the ranking procedure and their link to assist the decision process [49]. The indifference and preference threshold are two parameters which should be considered in this method and as a consequence small difference in a criterion cannot induce large differences in evaluations of FRMPs.

Application of various MCDMs have been reported studies in several water resources management plans [36, 51]. Moreover, several applications of MCDMs in water resources management shows that the models are proper means for making a decision in the area [1, 3, 5, 11, 19, 20]. Yang et al. [51] prioritized water management options for urbanization and climate change scenarios using the ELECTRE model. Purjavad and Shirouyehzad [43] compared three MCDM models, comprising ELECTRE, VIKOR and TOPSIS and conclude that these techniques had different outcomes.

Based on the literature review there were no comparison among compensatory semi-noncompensatory and noncompensatory models in water resources management study. Banihabib et al. [4] conclude that non-compensatory model has less sensitivity to criteria weights and therefore is more reliable in decision making for water shortage mitigation [4]. In water supply-demand strategies decision making, Cambrainha et al. [9] proved the robustness of non-compensatory models in the first three ranks of alternative options [9]. The non-compensatory MCDM models could also reflected the relative importance of the objectives established in integrated rehabilitation management scheme by Tscheikner-Gratl et al. [47, 48]. In this study, in addition to the compensatory and non-compensatory model, the semi-compensatory model is compared based on sensitivity analysis to the input models such as criteria weights value. Moreover, the comparison between MCDM models performed by both mathematical based and expert judgment based processes. Thus, the innovation of this research contains the comparison among these three groups with consideration of SDC attitudes. Sensitivity analysis in input data is important in MCDM evaluation [12]. Sensitivity analysis in IWA is another important issue which were neglected in most of the previous research. In so doing, the current research evaluate different IWA methods with different mathematical based.

In this paper, three models in different categories for applicability in sustainable flood management were evaluated. The VIKOR, ELECTRE I and PROMETHEE models were assessed in the ranking of FRMPs in the Gorganrood River in Iran. These models were compared using IWA sensitivity analysis and IW uncertainty evaluation to demonstrate relative strength and weaknesses. General objective of the research is to evaluate FRMPs with SDC using MCDM models in order to reduce flood damage in the study region. Main goals of the investigation are (I) A sets of SDC parameters were developed for various FRMPs; (II) Compensatory, semi-noncompensatory and noncompensatory MCDMs based on sensitivity analysis have been optimized, and (III) Commonalities and difference in optimal FRMPs have been evaluated.

2 Materials and methods

2.1 Study area

The Gorganrood River is north of Iran and the study reach of the river begins from Golestan-I Reservoir and extends to Gonbad-e Qabus City in the Golestan Province (Fig. 1). The population of the province is around 1.8 million, with a population density of approximately 88 individuals per square kilometer. The province had experienced more

than 60 floods in the last decade, causing 112 million U.S. dollars of damage and about 468 losses [2]. Insurance companies in Iran are offering general disaster insurance that covers flood as well. However, most people do not use it because of economic reasons.

Gorganrood Basin has 20,380 km² area and is bounded by 37°00'–37°30' north latitude and 54°00'–54°30' east longitude. Golestan Province is bordered by the Semnan, North Khorasan, and Mazandaran Provinces, and the Caspian Sea, and the Republic of Turkmenistan. Its land is covered by forests, range lands and farmlands. The case study area has high to moderate precipitation (250 to 450 mm) with absolute minimum and maximum daily temperature between – 1.4 and 46.5° C [22, 46].

2.2 FRMPs

The following structural and non-structural FRMPs are proposed for the Gorganrood River based on the physical, social and economic conditions of the study area [52]:

- FRMP #1: No project case (for contrasting with other FRMPs),
- FRMP #2: Flood peak alleviation by Golestan-I Reservoir,
- FRMP #3: Building levees in the study reach,

Fig. 1 Study area

FRMP #4: Building a diversion canal to protect the study area,
 FRMP #5: Designing a warning system,
 FRMP #6: Employing a flood insurance program,
 FRMP #7: Combining FRMPs #5 and #6.

In the FRMP #1 neither structural nor non-structural measures are implemented. Thus, this FRMP reflects environmental and socioeconomic impacts of flood in the current state of the region. FRMP #2 uses flood alleviation capacity of Golestan-I Reservoir, while water level of the reservoir is considered at normal level and used as an initial condition of flood routing of the reservoir. Therefore, construction, operation, maintenance costs and socioeconomic and environmental outcomes of Golestan-I Reservoir are deliberated in FRMP #2. The third FRMP applies levees to safeguard the study reach of the study area at a 50-year flood. Higher return period floods than this can increase the damages in the floodplain more than in natural state. This fact is reflected in the evaluation of criteria by the MCDM models. Based on the flood routing in the river, the levees' height are determined. The length, side-slopes and the crest width the of the levees equal to 41,150 m, 1/2 and 5 m, respectively. The FRMP #4 considers the construction of a flood diversion canal parallel to a width of 100 m and a depth of 3 m. If flow of this river exceeds 355 m³/s, this flood division canal can carry a surplus flow of as much as 204 m³/s. Thus, the reach is secured for floods up to a peak discharge of 559 m³/s. The FRMP #5 applies warning systems. Comparable to FRMP #1, no physical alterations would be considered under FRMP #5. The FRMP #6 applies flood insurance, which compensates flood damages and any casualties. Similarly, no physical alterations would be considered in the floodplain. Lastly, the FRMP #7 applies both FRMP #5 and FRMP #6. Each FRMP is prioritized based on SDC described below and applied in MCDMs to determine the best FRMP.

2.3 Proposed SDCs

There is interaction and conflict of concern between flood control and environment [38]. The SDCs (Criterion #1 To Criterion #11) were selected based on existing flooding literature relevant to the study and described below:

Criterion #1: *Expected Annual Damage (EAD)* is employed based on the amplitude of flood [8, 15, 16, 28, 30, 32, 36].

Criterion #2: *Recovery Rate (RR)* from the flood damages state to normal or better than normal state [8, 15, 32].

Criterion #9: *Gradual change* in system response (damage) to flood flow increase [15].

Criterion #4: It is *Expected Average Number of Casualties (EANC)* per year [8, 15, 28, 32, 36].

Criterion #5: *Feeling safe by people* due to applying a FRMP which assists the social satisfaction of the study area [28, 30].

Criterion #6: *Employment rate* which is a social satisfaction factor [16, 30].

Criterion #7: The level of people *participation* in applying an FRMP, a good criterion of social sustainability [18].

Criterion #8: The *protection of natural environment* which is a criterion of environmental sustainability [16, 30].

Criterion #9: The *wild life habitat conservation* as a criterion to assess the role of FRMPs in environmentally sustainable development [8, 16, 28, 32, 36].

Criterion #10: The *water quality conservation* to improve water resources and environment protection [8, 16, 32].

Criterion #11: The *technical feasibility and construction speed* which makes each FRMP different from other FRMPs in terms of economic feasibility and social satisfaction [16, 30, 32].

Criteria #1, #2, #9 and #11 have more observations than other criteria in published papers. Moreover, SDCs can be classified as qualitative and quantitative. The qualitative criteria are graded by expert, while quantitative criteria are determined using the formula below.

2.4 Evaluation of quantitative criteria

Quantitative criteria values were calculated using Eqs. (1–5). EANC, EAD, and graduality are quantitative criteria. De Bruijn [15] assessed them by following equations.

$$EAD = \int_{1/10000}^{P(D=0)} PD(P)dP \sqrt{a^2 + b^2} \quad (1)$$

$$EANC = \int_{1/10000}^{P(D=0)} PC(P)dP \quad (2)$$

where P is flood frequency, $D(P)$ is the expected damage as a function of flood frequency (€ million) and $C(P)$ is the number of dead as function of flood frequency [15].

$$Graduality = 1 - \sum_{n=1}^{n=N} \frac{|\Delta Q'_n - \Delta D'_n|}{200} \quad (3)$$

$$\Delta Q'_n = \left[\frac{100(Q_n - Q_{min})}{Q_{max} - Q_{min}} \right] - \left[\frac{100(Q_{n-1} - Q_{min})}{Q_{max} - Q_{min}} \right] \quad (4)$$

$$\Delta D'_n = \left[\frac{100(D_n - D_{\min})}{D_{\max} - D_{\min}} \right] - \left[\frac{100(D_{n-1} - D_{\min})}{D_{\max} - D_{\min}} \right] \quad (5)$$

where Q' is comparative discharge (%), Q is discharge (m^3/s), $Q_{\max} = Q(P = \frac{1}{10000})$, $Q_{\min}$ is the highest Q for which $D = 0$, D' is comparative damage (%), D is damage (€ million) as a function of Q , $D_{\max} = D(Q_{\max})$, $D_{\min} = 0$ and n is the rank number of the discharge level.

2.5 IWA method

In this section, the most common weighting methods as AHP (subjective method) and Entropy (objective method) are compared with a new approach in IWA methods. In AHP method, the results of the pair-wise comparison should be tested by consistency ratio and the satisfying results are obtained only if the judgments of experts are in concordance [53]. In Shannon's Entropy method, computational processes have the superiority to expert judgment [27, 34]. The results obtained by both of subjective and objective methods have number of benefits and shortcomings. Subjective methods reflect the expert judgment directly, while objective methods just use precise analytical methods. To address this issue, SWARA method is suggested by Keršuliene et al. [31] which is able to combine subjective and objective methods. Not only can SWARA use the expert priorities and precise analytical approaches together, but it also offers a chance to estimate the differences of criteria significances.

2.6 SWARA method

The first step in SWARA method is sorting criteria based on expert preferences and then evaluating the preferences of each criterion in comparison to the next one as the signification ratio, the parameter (k_j) in Eq. (6) Where j is the Criterion number and Comparative importance of average value [31].

$$k_j = \begin{cases} 1 & j = 1 \\ s_j + 1 & j > 1 \end{cases} \quad (6)$$

The following steps are determining initial weight (w_j) and final weight (q_j) of criteria from Eqs. (7) and (8) respectively.

$$w_j = \begin{cases} 1 & j = 1 \\ \frac{x_j - 1}{k_j} & j > 1 \end{cases} \quad (7)$$

$$q_j = \frac{w_j}{\sum_{k=1}^n w_k} \quad (8)$$

2.7 Compensatory MCDM model

VIKOR model, as a compensatory MCDM model, ranks by assessing the degree of closeness by the ideal solution. The model involves five steps:

- (1) Computing the standardized decision matrix as Eq. (9).

$$f_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^m x_{ij}^2}} \quad (9)$$

where f_{ij} is an element of standardized decision matrix and x_{ij} is the A th FRMP performance for j th criterion.

- (2) Calculating S (utility) and R (regret) by Eqs. (10) and (11) as follows:

$$S_i = \sum_{j=1}^n w_j \cdot \frac{f_j^* - f_{ij}}{f_j^* - f_j^-} \quad (10)$$

$$R_i = \max \left\{ w_j \cdot \frac{f_j^* - f_{ij}}{f_j^* - f_j^-} \right\} \quad (11)$$

where $f_j^* = \max f_{ij}$ and $f_j^- = \min f_{ij}$ for positive criteria, $f_j^* = \min f_{ij}$ and $f_j^- = \max f_{ij}$ for negative criteria and w_j is the weight of the criterion j . f_j^* is the ideal solution and f_j^- is the negative-ideal solution.

- (3) Calculating Q by Eq. (12).

$$Q_i = v \left[\frac{S_i - S^-}{S^* - S^-} \right] + (1 - v) \left[\frac{R_i - R^-}{R^* - R^-} \right] \quad (12)$$

where $S^- = \min S_i$, $S^* = \max S_i$, $R^- = \min R_i$, $R^* = \max R_i$ and v is defined as a weight of the strategy of "the majority of criteria" or "the maximum group utility". This parameter could be valued as 0–1 and when the $v > 0.5$, the criterion of Q will incline to majority rule.

- (4) Ranks of the FRMPs were sorted by considering the value of S , R and Q . The best FRMP has the least value of these three parameters.
- (5) The highest ranked FRMP in Q parameter would be the best FRMP if the two following conditions were satisfied:

$$C1 : Q(A_2) - Q(A_1) \geq \frac{1}{n-1} \quad (13)$$

where A_1 and A_2 are the FRMPs with first and second rank and n is the total number of the criteria.

- C2: FRMP that has the first rank in Q , should also have the first rank in S and R , or both of them.

If circumstance C2 is not fulfilled, set of FRMPs ranking would be $A_1, A_2, \dots, A_m$. Where A_m is defined by the Eq. (14).

$$(A_m) - Q(A_1) < \frac{1}{n-1} \quad (14)$$

If circumstance C1 is not fulfilled, A_1 and A_2 would be nominated as the best FRMP [41].

2.8 Semi-noncompensatory model

Semi-noncompensatory model, ELECTRE I model, uses the concept of an outranking relation, s , for modeling the preference. For instance, AsB express that A outranks B or A is at minimum as worthy as B in most of the criteria. First decision matrix normalized and remain process are as follows:

$$v_{ij} = w_j f_{ij} \quad (15)$$

- (1) Determining the concordance matrix in Eq. (16):

$$C_{ke} = \sum_{j \in S_{ke}} W_j \quad (16)$$

Where C_{ke} is sum of the weights of those criteria where FRMP k outranks FRMP e and W_j is weight of criteria j .

- (2) Computing the discordance matrix as Eq. (17).

$$d_{ke} = \frac{\max_{j \in I_{ke}} |V_{kj} - V_{ej}|}{\max_{j \in J} |V_{kj} - V_{ej}|} \quad (17)$$

where $I_{ke} = J - S_{ke}$, and V_{ij} is the weighted standardized matrix component.

- (3) Computing concordance dominance matrix as Eqs. (18) and (19).

$$f_{ke} = \begin{cases} 1 & C_{ke} \geq \bar{C} \\ 0 & C_{ke} < \bar{C} \end{cases} \quad (18)$$

$$\bar{C} = \sum_{k=1}^m \sum_{\substack{e=1 \\ k \neq e}}^m \frac{C_{ke}}{m(m-1)} \quad (19)$$

- (4) Computing discordance dominance matrix as Eq. (20).

$$g_{ke} = \begin{cases} 0 & d_{ke} > \bar{d} \\ 1 & d_{ke} \leq \bar{d} \end{cases} \quad (20)$$

$$\bar{d} = \sum_{k=1}^m \sum_{\substack{e=1 \\ k \neq e}}^m \frac{d_{ke}}{m(m-1)} \quad (21)$$

- (5) Calculating final dominance matrix as Eq. (22).

$$h_{ke} = f_{ke} \cdot g_{ke} \quad (22)$$

- (6) Choosing the best FRMP: in final dominance matrix, numbers show dominance of the FRMPs in each row and beaten of the FRMPs in each column. The FRMP with less difference in sum of row and sum of column, is placed in the higher rank.

2.9 PROMETHEE method

PROMETHEE method calculate the net flow between two FRMPs A_i and A_j which is defined as in Eq. (23) [7].

$$\Phi_{ij} = \sum_k w_k f(a_{ik} - a_{jk}) \quad (23)$$

where w_k is the criteria' weight defined by experts and f is the preferential function as Eq. (24).

$$f(d) = \begin{cases} 0 & d \leq t_{ind} \\ (d - t_{ind}) / (t_{pref} - t_{ind}) & t_{ind} < d \leq t_{pref} \\ 1 & d > t_{pref} \end{cases} \quad (24)$$

where t_{ind} is the indifference threshold, which is the largest deviation for each criterion, and can be neglected in criteria domination on others, and t_{pref} is the preference threshold, which is the smallest deviation for each criterion, and define the criteria domination on other criteria. Then, the outflow inflow and net flow are determined as Eq. (25) which the FRMPs ranking can be defined as net flow value the FRMP with higher net flow set in the highest rank.

$$\begin{aligned} \text{Outflow: } \Phi_i^+ &= \sum_j \Phi_{ij} \\ \text{Inflow: } \Phi_i^- &= \sum_j \Phi_{ji} \\ \text{Netflow: } \Phi_i &= \Phi_i^+ - \Phi_i^- \end{aligned} \quad (25)$$

2.10 Sensitivity analysis of IW

In order to assess the sensitivity of ranking to weights, the weight of each criterion is descended from minimum to maximum levels, and variation in ranking is examined. Summation of the weights is maintained to equal to one.

Thus, every change in the weight of each criterion can cause changes in other weights as Eq. (26).

$$W'_j = \frac{1 - W'_i}{1 - W_i} \times W_j \quad (26)$$

where W'_i is the new weight of criterion i in sensitivity analysis, W_i previous weight of criterion i , W_j previous weight of criterion j and W'_j is improved weight of criterion j .

3 Results and discussion

3.1 IW results

In this paper, weights and FRMP scores of qualitative criteria were determined based on a questionnaire survey of 30 experts in water engineering. These experts are from local and state water resources and watershed management organizations, private companies, and universities. Their familiarity with the region and its flood problems are evaluated to be high through questionnaires. The results of expert elucidation for quantitative criteria and the outcomes of qualitative criteria are obtainable in Table 1.

3.2 Results of IWA methods

Different IWA methods released unlike results based on their computational processes. Table 2 show that Shannon's Entropy as an objective method cannot justify IW due to ignoring expert preferences. However, AHP and SWARA methods outperform Shannon's Entropy method because they are able to reflect expert priorities as well as decision matrix data. Another remarkable point is that Shannon's Entropy method emphasize on the standard deviation in decision matrix. These result assert that Shannon's Entropy method focuses more on the mathematical calculation, but AHP and SWARA keep a balance between

Table 2 The results of IWA methods

Criteria No	AHP	SWARA	Shannon's entropy	SD
Criterion #1	0.090	0.086	0.081	0.050
Criterion #2	0.110	0.157	0.003	0.010
Criterion #3	0.050	0.014	0.002	0.010
Criterion #4	0.310	0.399	0.100	0.053
Criterion #5	0.175	0.255	0.101	0.052
Criterion #6	0.030	0.004	0.422	0.178
Criterion #7	0.050	0.007	0.021	0.028
Criterion #8	0.020	0.001	0.069	0.057
Criterion #9	0.065	0.025	0.055	0.045
Criterion #10	0.070	0.048	0.117	0.066
Criterion #11	0.030	0.002	0.027	0.031

expert judgment and mathematical calculation. As can be seen in Table 2, criteria with higher standard deviation has a higher value in Shannon's Entropy method.

3.3 Results of MCDM models

3.3.1 MCDM results based on different IWA methods

The results of MCDM models with different IWA methods are shown in Table 3. Changes in IWA methods caused different results in FRMP ranks. In all MCDM models, AHP and SWARA methods had approximately the same results, while Shannon's Entropy had a variety in results. Consequently, the superiority of SWARA and AHP method in this research, asserted due to the stable results in different MCDM models. In addition, VIKOR (with $\nu = 0.5$) as a compensatory model had the same results with AHP and SWARA methods. ELECTRE and PREMETHHEE methods had few changes, so semi-noncompensatory and

Table 1 Decision matrix

Criteria	FRMP1	FRMP2	FRMP3	FRMP4	FRMP5	FRMP6	FRMP7	t_{ind}	t_{pref}
Criterion #1	11,792	17767	12,574	2865	12,083	11,792	12,083	1000	3000
Criterion #2	5.7	6	5.7	5.7	6.3	6.7	6.7	1	2
Criterion #9	0.83	0.8	0.73	0.94	0.86	0.83	0.83	0.05	0.1
Criterion #4	4.4	1.9	3.8	2.2	2	4.4	2	0.2	1
Criterion #5	1	4	3	3.5	4	2.5	5	0.5	2
Criterion #6	1	0.6	0.9	5.8	0.4	1	0.4	0.2	1
Criterion #7	2	3	3	3	3.5	2.5	4	0.2	1
Criterion #8	3	5	1	2	4	3	4	1	2
Criterion #9	4	2	2	2	4	4	4	1	2
Criterion #10	1	5	2.8	3	2	2	2	0.5	1
Criterion #11	4	2	3	2.5	4	3.5	3	0.5	1

Table 3 The results of MCDM models with different IWA methods

FRMP	VIKOR ($\alpha = 0.5$)			ELECTRE I			PROMETHEE		
	AHP	SWARA	Entropy	AHP	SWARA	Entropy	AHP	SWARA	Entropy
#1	6	6	7	5	6	5	7	7	7
#2	2	2	2	1	2	3	4	2	2
#3	4	4	6	4	4	4	6	5	6
#4	3	3	1	2	3	1	3	4	1
#5	1	1	4	3	3	7	2	3	5
#6	5	5	5	4	5	2	5	6	3
#7	1	1	3	1	1	6	1	1	4

noncompensatory models were less sensitive to any change in IWA methods.

The sensitivity analysis assessed based on the α parameter in VIKOR model and thresholds in the PROMETHEE model. The PROMETHEE model had no sensitivity to its indifference and preference thresholds. Although VIKOR method had no sensitivity in IWA models, the changes in α parameter affected the final results in this model as Table 4. SWARA-VIKOR had no sensitivity to α parameter but AHP-VIKOR had different results for $\alpha = 0.8$ and $\alpha = 0.9$. Shannon's Entropy-VIKOR had high sensitivity in different α parameter.

3.3.2 Different MCDM model results in FRMP and IW uncertainty

In order to measuring the different MCDM models in FRMP, the SWARA results was used as a benchmark in this part of calculation. Based on the results in SWARA-VIKOR model in Table 3, designing a warning system solely and the combination of designing a warning system and employing a flood insurance program were in the first priority, flood peak alleviation by Golestan-I reservoir was in the second rank, building a diversion canal and levees were in the third and fourth rank, and employing a flood insurance program was in the last priority. In SWARA-ELECTRE I the combination of designing a warning system and employing a flood insurance program was in the first rank, flood peak alleviation by Golestan-I

reservoir was in the second rank, building a diversion canal and designing a warning system were in the third rank, building a levees in the study area and employing a flood insurance program were in fourth and fifth ranks. Based on the SWARA-PROMETHEE model the combination of designing the warning system and employing a flood insurance program was in the first rank, flood peak alleviation by Golestan-I reservoir was in the second rank, designing a warning system was in the third rank, building a diversion canal and levees in the study area were fourth and fifth rank, respectively. Employing a flood insurance program was in the last priority by SWARA-PROMETHEE model.

Different IW are evaluated by expert judgment as an input data. Thus, sensitivity analysis is necessary to assess the uncertainties in IW value. For this purpose, the maximum and minimum in IW in expert's questionnaires were used as Table 5. The Eq. (26) was used to improve other IW in each maximization and minimization. Table 6 shows the changes in MCDM results which were affected by different IW. Based on the changes in IW, VIKOR model had high sensitivity in six IW as Max Criterion #1, Max Criterion #2, Min Criterion #2, Max Criterion #3, Max Criterion #6 and Max Criterion #10. ELECTRE model showed different results for five IW as Max Criterion #2, Max Criterion #3, Min Criterion #4, Max Criterion #9 and Min Criterion #10, but these slight changes did not appear in important ranks. Due to the IW results in Table 2, Criterion #1, Criterion #2 and Criterion #4 had the highest value in SDC assessment in this research,

Table 4 Changes in VIKOR results by different α value

FRMP	AHP-VIKOR		Shannon's Entropy-VIKOR				
	$\alpha = 0.1-0.7$	$\alpha = 0.8-0.9$	$\alpha = 0.1$	$\alpha = 0.2$	$\alpha = 0.3$	$\alpha = 0.4-0.6$	$\alpha = 0.7-0.9$
#1	6	7	3	4	6	7	7
#2	2	4	5	3	2	2	3
#3	4	6	4	5	7	6	6
#4	3	3	1	1	1	1	1
#5	1	2	7	7	5	4	4
#6	5	5	2	2	3	5	5
#7	1	1	6	6	4	3	2

Table 5 Maximum and minimum value of IW

Criteria	Maximum of weights	Minimum of weights
Criterion #1	0.18	0.021
Criterion #2	0.19	0.023
Criterion #3	0.16	0.021
Criterion #4	0.36	0.11
Criterion #5	0.3	0.1
Criterion #6	0.1	0.012
Criterion #7	0.19	0.012
Criterion #8	0.08	0.013
Criterion #9	0.19	0.02
Criterion #10	0.15	0.02
Criterion #11	0.1	0.012

while VIKOR and ELECTREE models showed sensitivity to these important criteria.

However, in all of MCDM methods FRMP #7 (the combination of using a flood warning system and applying a flood insurance) was in first rank as a non-structural strategy, variation of Techno-economic and environmental criteria in VIKOR method promoted like FRMPs #4 and #2 as structural measures to the first rank. Therefore, the result of VIKOR model was sensitive to the variation in IW and caused a conflict between structural and non-structural FRMPs for the first rank. The ELECTREE I model selected FRMP #7 a non-structural measure in all IW changes. The PROMETHEE model had better

results in comparison to other MCDMs. It showed sensitivity only for the Criterion #6 and Criterion #11 which were not valuable criteria among other SDC and these few changes in FRMPs priority were not relate to the conflict between structural and non-structural FRMPs. Therefore, MCDM results in different IW prove that PROMETHEE as a non-compensatory model was able to release more stable results in various IW for flood management in the case study area.

4 Conclusion

To assess the structural and nonstructural flood risk FRMPs in Gorganrood River, Golestan province of Iran, SDCs approach was useful to incorporate sustainability criteria into flood management. In this paper, seven FRMPs were ranked by three different groups of MCDM models as VIKOR, ELECTRE I, and PROMETHEE. In addition, different IWA methods as AHP, SWARA, and Shannon's Entropy were employed to evaluate criteria. The sensitivity and uncertainty analysis assessed the efficiency of MCDM models as well as IWA methods. The results in IWA and the concordance results between the MCDMs, the dominance of SWARA, as a new weighing method, and the deficiency of Shannon's Entropy, as one of the most common weighting methods, were proved. This process highlighted the combination of mathematical technique and expert judgment in SWARA as IWA method. The changes in IWA methods emphasized the sensitivity of VIKOR method

Table 6 MCDM results based on different IW

	#1	#2	#3	#4	#5	#6	#7
<i>SWARA-VIKOR</i>							
No changes in weights	6	2	4	3	1	5	1
Max Criterion #1	6	3	4	2	1	5	1
Max Criterion #2	6	2	5	3	1	4	1
Min Criterion #2	6	4	3	2	1	5	1
Max Criterion #3	5	2	4	1	1	3	1
Max Criterion #6	5	2	3	1	1	4	1
Max Criterion #10	4	1	2	1	1	3	1
<i>SWARA-ELECTRE I</i>							
No changes in weights	6	2	4	3	3	5	1
Max Criterion #2	6	3	5	2	3	4	1
Max Criterion #3	6	3	5	2	3	4	1
Min Criterion #4	6	3	5	2	3	4	1
Max Criterion #9	7	4	6	3	2	5	1
Min Criterion #10	5	3	4	2	2	4	1
<i>SWARA-PROMETHEE</i>							
No changes in weights	7	2	5	4	3	6	1
Max Criterion #6	7	3	5	2	4	6	1
Max Criterion #11	7	3	5	4	2	6	1

due to the α parameter. This compensatory model had also varied results in IW changes for important criteria, while ELECTRE I and PROMETHEE models had more stable results especially in priority of FRMP #7 (the combination of flood warning system and flood insurance) as a non-structural FRMP. Based on the IW uncertainty along with sensitivity analysis to IWA methods, SWARA-PROMETHEE as noncompensatory method could be a robust technique to improve the flood management with consideration of SDCs approaches in this case study and this outcome may be applied in flood management based on sustainable development concept in other river basins.

For future works developing a spatial probabilistic multi-criteria structure to prioritize the FRMPs with consideration of hydraulic and hydrology uncertainties are recommended. Assessing the effects of flood factors such as depth, velocity, duration, and arrival time and canal and watershed characteristics as decision criteria can assist decision makers to realize the uncertainty in selection of FRMPs. In addition, a comprehensive comparison among other MCDM techniques is essential to verify or corroborate this study outcome.

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Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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