Flood Risk Management Using MCDM Systems

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Abstract

Economic and social losses due to flood are diligently increasing. Although, traditional procedures had emphasized on flood control and on decreasing flood by means of usual structural approaches, however, in new procedures of management, the emphasis is on decreasing the flood consequences that is called flood risk management. To quantify the concept of resiliency, some criteria should be introduced. The multiple criteria decision making system (MCDM) is used as a tool for supporting the decision makers for prioritizing and making decisions about choosing the proper strategies. In this paper, MCDM system is used to study flood management in a part of the Basin of Gorgan River, (north of Iran) from downstream of Golestan 1 dam to the downstream of the city of Gonbad. Seven strategies consist of resistance and resilient, and structural and nonstructural strategies are introduced.

Resiliency attributes must be considered including amplitude, graduality and recovery rate. Flow hydraulics is evaluated by modeling the flood in return periods of 2 to 10000 years. Finally, by using of MCDM method, those scenarios are ranked by using of compensatory methods of MCDM. Priorities and sensibility of the results is also analyzed to rank the risk management strategies.

Key words: Risk management, MCDM, Flooding, Resiliency attributes

1. Introduction

The body of the paper begins with the Introduction. In the Introduction, state the purpose of the paper or the author's aim and a brief review of the literature in order to provide the reader with a clear concept of the objective(s). According to the current information and statistical data, the flood is one of the most lethal disasters throughout the world and based on loss of life and the community influenced by, it is very important. Increasing trend in flood occurrence is very worrying because of population growth, global warming phenomenon and increasing effects of the greenhouse gases. Iran is a high risk and vulnerable region in terms of disaster occurrence distribution caused by the flood. There are two methods, resistance and resilience, in flood risk management in order to achieve sustainable development. Considering the whole river basin as a system, its reaction mode to the surges caused by the flood represents the system resilience and resistance. It can be defined that resilience is the ability of flood-stricken areas to confront the flood by retrieval, in other words, to return to recent normal conditions. On the other hand, resistance is ability of the system to stand out against turbulence without any reaction.

In recent decades, the system resilience against the flood has gradually decreased and this will ultimately cause to unexpected system collapse. Therefore, the policies should be inclined to increase the system resilience to achieve sustainable development. With the modern approach in the flood risk management, resilient strategies should be considered specially. To quantify the resilience concept which causes to increase physical, economic and social system tolerance against flood, prior investigators have defined some attributes. Multiple criteria decision making systems is implemented as a tool to prioritize different resilient strategies raised in the flood management. Evaluating the attributes available in each strategy in multiple criteria decision making, the alternates or strategies will be prioritized.

1.1 .Generals, definitions and concepts

Natural disaster is catastrophe or tragedy resulted from occurring high risk natural phenomenon such as flooding, earthquake, land slide, storm or volcano which leads to incur life and financial losses in communities. In the regions without human interests, these natural events will no longer be converted to disaster. Based on World Bank report, damages resulted from natural disasters, especially in developing countries, will be imposed on poor communities. The studies indicate that poor people are most resident in vulnerable regions like flood plains, river coastlines, steep slopes and reclamations.

The flood is water overflow or surcharge surrounding and proceeding into the mainland. When high precipitation or snow melting lead to increase water depth in the river and the water is surcharged from river coastlines, large volumes of water will surround deep flood plains adjacent to the river. This phenomenon will be called the flood. According to the current statistical data, from 1950 till now, on average more than 170000 people in the country have annually been influenced by flood events and 242 people have lost their lives. Also, average annual financial damages caused by flood events have been estimated about 220 million dollars (1980 billion RLS) which is 0.125 percent of total national budget in 1384 and is 15.2 percent of water division in that year. This data indicates increasing trend in flood event frequency as well as incurred life and financial losses in the country. This is a warning for natural disaster decision makers and authorities to improve this crisis as faster as possible by modifying natural disaster management strategies from crisis management to risk management.

1.2 Traditional flood management strategies

The flood is one of the most common and destructive natural disaster in the world and our country is no exception. Macro management in the country seeks to react, subsequently compensate damages and reconstruction in order to reduce losses incurred by natural disaster events.

This management has two major drawbacks, grate losses and damages at first and further spending high financial resources to compensate losses such that in most recent years, about

70 percent of annual credits concerning to natural disaster effects decline plan as well as unexpected disaster headquarters have been spend on damages imposed by the flood. Traditionally, the efforts have been concentrated on decreasing flood risk, organizing rivers and constructing protection dikes. Such methods are applied aimed at reducing flood risks. These strategies in the flood management are called flood control strategies or resistance strategies.

1.3 Flood risk management

Flood risk management is one of principles in sustainable development. It means that environmental, economic and social processes should be considered in flood risk management. Sustainable development requires optimum use of the environment, establishing moderation for all social communities in the present and future, and conserving natural resources. In addition, a system, in order to sustain, should have ability to tolerate unknown turbulences such as severe floods and flow fluctuations. How to tolerate severe floods is the main subject in flood risk management. Flood risk is a function of flood dangers on one hand and on the other hand, is a function of consequences occurring after the flood. Minimizing consequences after occurrence of the flood or in other words learning to live with floods rather than reducing flood dangers is another to reduce flood risks. Such techniques are called resilience strategies. This methods are relied upon risk management rather than controlling the flood dangers.

1.4 Resilience strategies of flood management

Generally, different flood management methods could be classified in 4 groups:

- The efforts to downsize the flood
- The efforts to reduce vulnerability against the flood
- The efforts to decrease the losses
- Readiness to tolerate damages

First group is based on physical preservation by means of structures which are called structural methods. Other three groups are classified as nonstructural methods. In the other words, it can be said that structural methods are applied before the flood occurrence, mainly have structural nature and are implemented to keep away the people from the flood.

All methods to reduce flood problems which simultaneously include none of three abovementioned features are referred to nonstructural methods. Other methods including flood warning and discharging residents, which are implemented to keep away the people from the flood have nonstructural nature.

Flood experts believe that combining structural and nonstructural methods is the optimum solution to minimize flood damages. However, this combination is more cost effective than just structural methods. In fact it can be said that resilience strategies of flood management are mainly a combination of structural and nonstructural methods.

Various suggested strategies in flood management during mentioned study period are:

- Strategy 1- natural conditions
- Strategy 2- Golestan Dam 1
- Strategy 3- earth embankments on both sides of river
- Strategy 4- flood diversion canal in line with the river (Green River)
- Strategy 5- flood warning system
- Strategy 6- flood insurance

- Strategy 7- warning system and flood insurance together

1.5 quantifying resilience concept using applied features

De Bruijn (2005) tried to define and explain new features to determine the resilience of the flood risk management systems. To suitable and comprehensive quantifying the resilience, some features are required for each three aspects of amplitude, graduality in increasing reaction with increasing rate and recovery rate of the flood effects, which all of them express the reaction of a system against the floods.

1.5.1 Amplitude

Reaction amplitude to the flood surges represents the magnitude of expected effects resulted from a specific flood surge right after the flood event. In order to explain the magnitude of a system reaction to general flood surge regimes, annual expected damages have been suggested. To calculate annual expected damages, the relationship among all possible flood surges, their occurrence possibility and their mutual influences should be determined. In order to establish the possibility to compare different river systems, desired range for flood surge is confined to the rates between maximum rate with no damages and the rate with return period 10000.
De Bruijn suggested two features to estimate the reaction amplitude which are Expected Annual Damage (EAD) and Expected Average Number of Causalities per year (EANC).
The relations to estimate above features are as follows:

$$EAD = \int_{1/10000}^{P(D=0)} PD(P)dP \tag{1}$$

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

Where:
EAD: expected average damages per year (RLS per year)
EANC: expected average number of causalities per year (people per year)
P: flood occurrence possibility
D (P): the amount of expected damages as a function of possibility (currencies)
C (P): the amount of casualties in the form of possibility function (persons)
More, the methods applied to estimate EAD and EANC will be reviewed in this study.

1.5.2 Graduality

Graduality in increasing reaction with increasing rate indicates increasing the amount of damages with increasing flood surge dimensions. This increase is no longer constant but represents discontinuities in which low increasing the rate will greatly cause to increase incurred damages. Such condition, for example, will happen in embankment fractures. De Bruijn introduced adjusted Gini coefficient as a suitable indicator to determine Graduality in increasing reaction with increasing rate and suggested following relations to determine its amount.

1.5.3 Recovery rate

Recovery rate explains the return rate, from a condition in which the influences incurred by the flood are evident, to the normal conditions. This normal position or condition includes the conditions before flood occurrence or even better conditions.
Since there are differences in recovery rate between different social groups and different locations and also recovery rate is dependent on the relations with adjacent regions as well, therefore, quantifying the recovery ate is very difficult.
Based on this, De Bruijn presented a simplified quantity framework by means of which it can be possible to evaluate recovery rate of a system. Based on his opinion, recovery capacity of a flood risk management system is dependent on different physical, economic and social factors. (Fig. 1)

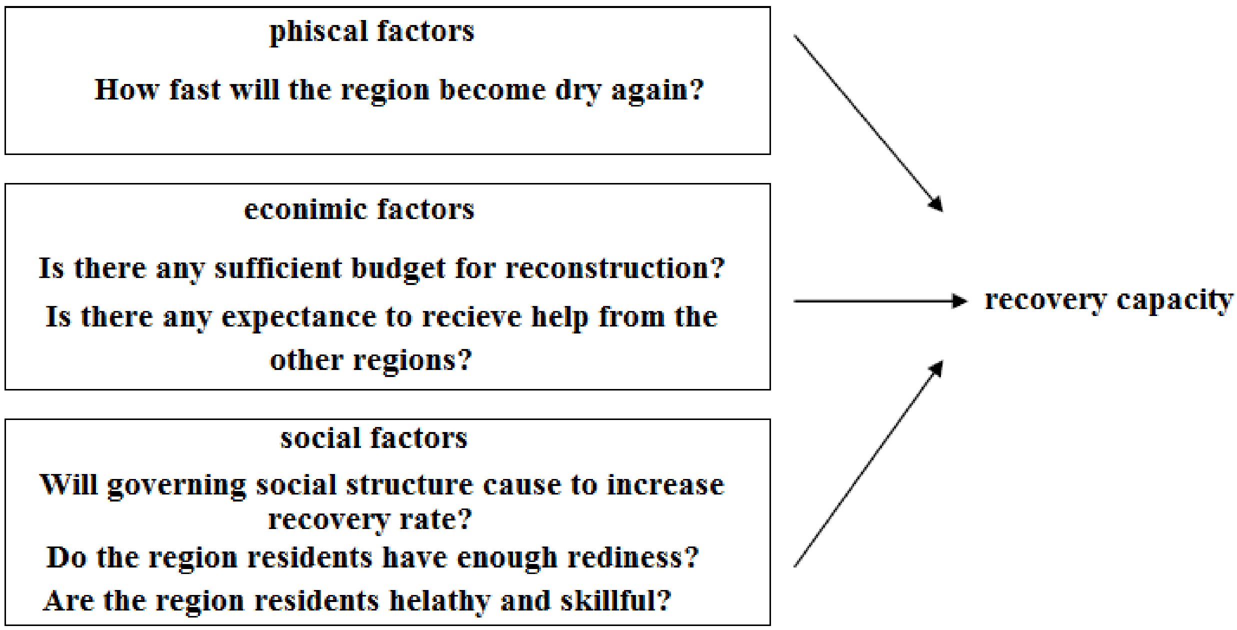


Figure 1: Determinant factors of recovery capacity

2. Application of multiple criteria decision making systems in flood management

MCDM is a set of methods to compare and classify multiple choice alternates that include incomparable characteristics. More important is that MCDM techniques are able to handle quality variables (e.g. direct water damage which cause to buildings and estates being soaked) and quantity variables (e.g. damage to the ecosystem and region environment) and ultimately, they sequentially classify a set of suggested alternates from the highest to the lowest priority. Although flood risk management process has been extensively discussed in the international and national levels, still more efforts are required to evaluate priorities, requirements and changing value systems related to effective factors in flood management process.
Information aggregation, flood monitoring, communication and computational technology, DSS, can greatly make coordination and fitness between businesses, related (to the flood and its influences) organizations and affected citizens. Key elements including flood database, flood modeling functions and user graphic interfaces can make complex flood risk management problems possible and applied by MCDM.

In this discussion MADM model was selected and formulated in the form of decision making matrix as follows:

$$D = \begin{array}{c} criteria \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{cccc} x_1 & x_2 & \cdots & x_n \\ \hline r_{11} & r_{12} & \ldots & r_{1n} \\ r_{21} & r_{22} & \ldots & r_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{array}$$

Table 1: Decision Matrix

A1,A2,…..Am in the decision making matrix D respectively constitute m already known alternates such as flood warning system, earth embankment on both sides of the river and etc. X1, X2,…..,Xn represent n features (or indices) including graduality reaction amplitude, recovery rate and etc to measure desirability of each alternates and finally rij represents specific values of jth feature for ith alternate. Xj features might be quantity like gradualtiy and/or quality like recovery rate. After discussing primitive concepts, they will expansively dealth with.

2.1 simple additive weighting method (SAW)

This method is one of the oldest applied methods in MADM such that assuming the vector W, the most apropriate alternate A* will be calculated as follows.

$$A^* = \left\{ A_i \middle| \ \max_i \frac{\sum_j w_j . r_{ij}}{\sum_j w_j} \right\} \tag{3}$$

This method requires similar scales or normalized measurements which can be compared together. The most important assumption applied in this method is relied upon priority indipendency and differentiating the effects of features from each other. Generally applying desirability or value forms requires existing priority independency among the features at least.

3. Case study

Gorganrood river basin has the area about 11300 km2 and its annual average discharge is about 3.5 billion m3. Studied area is a section of Gorganrood river which is extended from Golestan dam 1 downstream to the Gonbad city downstream. This section is divided into two major parts. The first part of the section is extended from Golestan dam 1 downstream to river enterance in Gonbad whose flood plain has rural and agricultural applications. The second part of Gorganrood river is located in urban regions of Gonbad and its specific urban applications to evaluate the flood risk wil be reviewed.

4. Flood modeling and zoning in different strategies

Flood modeling and zoning in diferent strategies and with return periods 2, 5, 10, 25, 50, 100, 200, 500, 1000, 2000, 5000 and 10000 years have been performed using MIKE FLOOD model. Based on obtained zonings, damages incured by the flood have been estimated for each strategy and have converted to annual costs using engineering economics relations. Also, according to obtained zonings for flow depth and velocity, the vulnerable community affecting by the flood, the amount of losses and injured people in aggregate have been estimated and expected annual amount of life losses have been obtained. Finally using obtained zonings, also graduality index will quantitatively be expressed by the relations concerning to the Gein coefficient and recovery rate factor by engineering judgement.

5. Multiple criteria analysis results MCA1, total weighting, median standardization, direct weighting method

In this case, antropy technique has been used to import criterion weightings. At first, decision making matrix was standardized by linear method. Next, degree of deviations in the evaluation values was obtained and finally criterion weightings W were calculated and directly imported into MCA1. How to calculate the weightings W is presented in the table below.

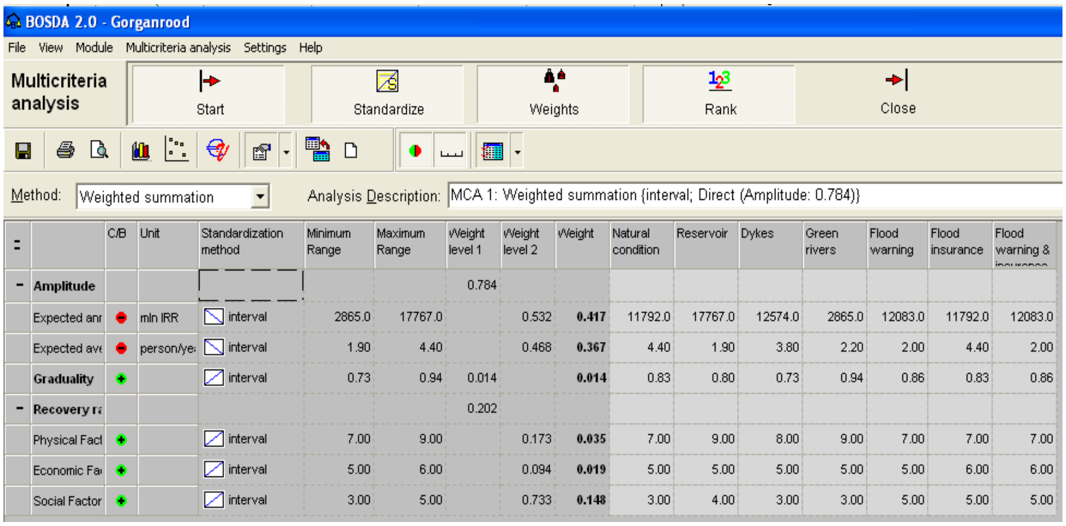
		Criteria					
		EAD (Milion Rial Per Year)	EANC (Person in Year)	Graduality	Physical Factors	Economic Factors	Social Factors
		C1	C2	C3	C4	C5	C6
Alternatives	S1	11792	4.4	0.83	7	5	3
	S2	17767	1.9	0.8	9	5	4
	S3	12574	3.8	0.73	8	5	3
	S4	2865	2.2	0.94	9	5	3
	S5	12083	2	0.86	7	5	5
	S6	11792	4.4	0.83	7	6	5
	S7	12083	2	0.86	7	6	5

Table 2: evaluation values in different strategies

W1	W2	W3	W4	W5	W6
0.417319	0.367148	0.013744	0.034828	0.019411	0.14755

Table 3: weightings against decision making attributes

Prioritizing mentioned strategies for flood risk management in the case study has been performed using multiple criteria decision making method as well as DEFINITE software. Decision making matrix is constructed directly importing the weightings, in other words, quantitative weighting is performed as follows.



		C/B	Unit	Standardization method	Minimum Range	Maximum Range	Weight level 1	Weight level 2	Weight	Natural condition	Reservoir	Dykes	Green rivers	Flood warning	Flood insurance	Flood warning & insurance
-	**Amplitude**						0.784									
	Expected anr	−	mln IRR	interval	2865.0	17767.0		0.532	**0.417**	11792.0	17767.0	12574.0	2865.0	12083.0	11792.0	12083.0
	Expected ave	−	person/yea	interval	1.90	4.40		0.468	**0.367**	4.40	1.90	3.80	2.20	2.00	4.40	2.00
	Graduality	+		interval	0.73	0.94	0.014		**0.014**	0.83	0.80	0.73	0.94	0.86	0.83	0.86
-	**Recovery ra**						0.202									
	Physical Fact	+		interval	7.00	9.00		0.173	**0.035**	7.00	9.00	8.00	9.00	7.00	7.00	7.00
	Economic Fa	+		interval	5.00	6.00		0.094	**0.019**	5.00	5.00	5.00	5.00	5.00	6.00	6.00
	Social Factor	+		interval	3.00	5.00		0.733	**0.148**	3.00	4.00	3.00	3.00	5.00	5.00	5.00

Figure 2: decision matrix for MCA1 analysis based on direct weighting method

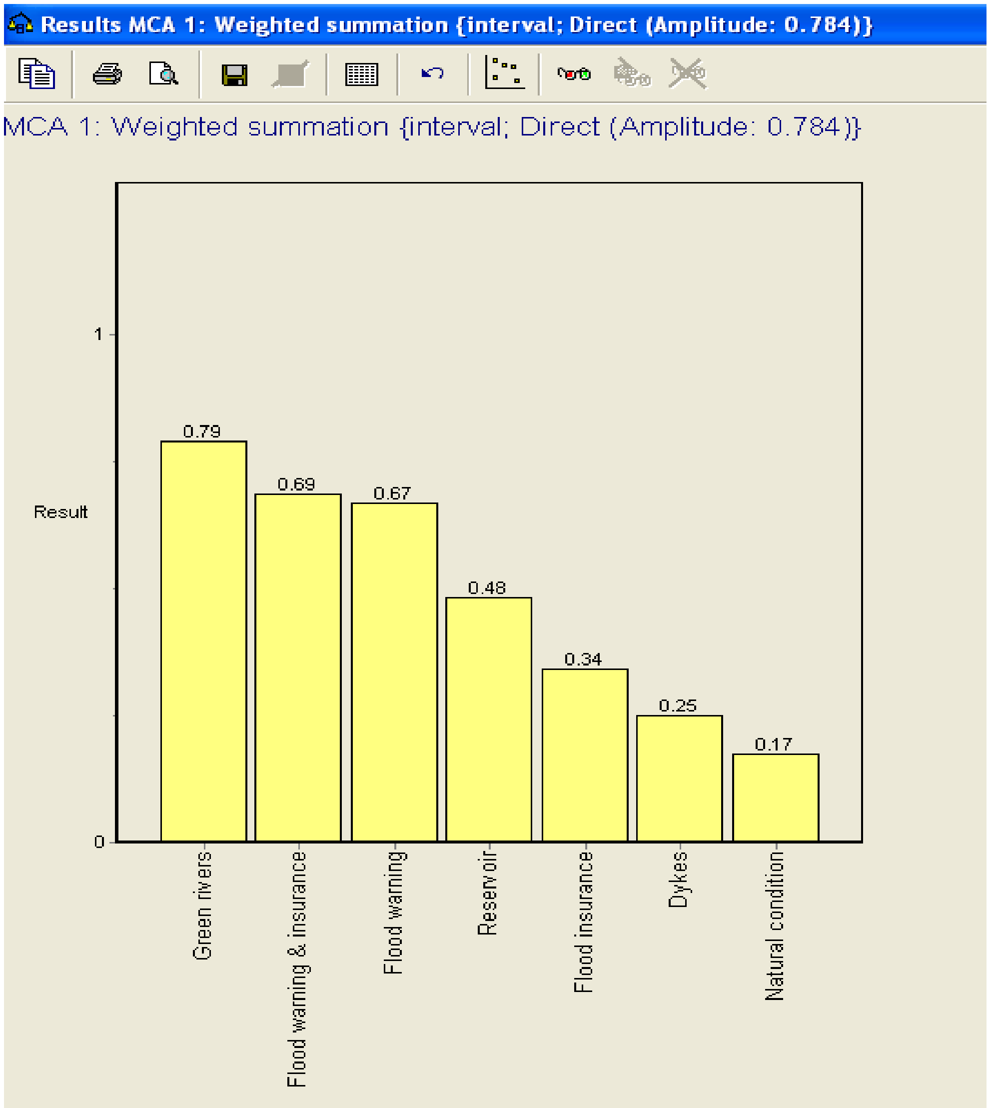


Figure 3: the results of prioritizing strategies in MCA1 analysis based on direct weighting method

This results demonstrate that deviation canal, warning system and flood insurance strategies are the most appropriate alternates based on defined criteria. Also, flood warning system and Golestan dam 1 strategies are subsequent alternates by higher scores than other alternates. Natural conditions and embankment alternates have the least scores.

In order to review priority change mode with changing criteria weightings and values, sensitivity analysis considering 20 percent uncertainty for them was performed nd the results have been illustrated in the following figure.

According to these results, the deviatory canal alternate is located in first, second and third priority by 87, .. and 5 percent in the events respectively and this indicates emphasizing on this alternate in majority events in view of desired criteria and other alternates no longer position in the first priority. Golestan dam in 99 percent of events positions in the fourth priority.

Probability table

[WghtUnc.: 20.00 %; ScorUnc.: 20.00 %]

Alternatives/Positions	1	2	3	4	5	6	7	Total
Green rivers	0.870	0.080	0.050	0.000	0.000	0.000	0.000	6.820
Flood warning & insurance	0.060	0.620	0.320	0.000	0.000	0.000	0.000	5.740
Flood warning	0.070	0.300	0.630	0.000	0.000	0.000	0.000	5.440
Reservoir	0.000	0.000	0.000	0.990	0.010	0.000	0.000	3.990
Flood insurance	0.000	0.000	0.000	0.010	0.990	0.000	0.000	3.010
Dykes	0.000	0.000	0.000	0.000	0.000	1.000	0.000	2.000
Natural condition	0.000	0.000	0.000	0.000	0.000	0.000	1.000	1.000

Figure 4: sensitivity analysis results for MCA1 with 20 percent uncertainty

6. Conclusions

The conclusions of this study show that applying resilience and resistance concepts in flood risk management requires a systematic perspective. Flood risk management system includes river basin, flood plain and also physical, economic and social characteristics.

Considering the results obtained from applying multiple criteria decision making methods in this study, their importance in complex decisions in water resources management subjects such as selecting appropriate strategies for flood management, creating a tool to prioritize available alternatives under different conditions and applying these methods as suitable tools to support decision makers will be clarified.

In this paper, seven different strategies including structural and nonstructural strategies in the case study (a section of Gorganrood river basin) have been assessed and prioritized and compared by multiple criteria decision making methods as well as resilience point of view. These seven strategies are natural conditions, Golestan dam, embankment, flood deviatory canal, flood warning system, flood insurance and flood insurance together with warning system. Prioritizing mentioned alternatives by multiple criteria decision making methods, deviatory canal strategy (strategy 4) has been selected as the most appropriate strategy in terms of resilience. Therefore, as it can be observed, selected strategy is of strategies that will cause to decrease the consequences after flood occurrence or to create living with the flood point of view which is one of the characteristics of resilience strategies. Also, resistance strategy of embankment (strategy 3) which is aimed to prevent flood occurrence rather than to decrease the consequences after flood occurrence, has no longer achieved a suitable priority.

Golestan dam is aimed to flood control and provide agricultural water, although its irrigation network has not still been completed. Therefore, at the moment the only main purpose of Golestan dam is flood control that never would be cost effective and this point indicates the importance of studies before performing the plan and this will double the emphasize on using multiple criteria decision making methods.

Natural condition strategy obtained the last priority because of high expected annual losses. This situation was resulted from locating urban and rural resident regions in the flood plain which necessitates changing land use.

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