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Environmental Risk Management of Eyvashan Dam Using Traditional-FMEA and FIS-FMEA Methods

Behrang Beiranvand[1*], Taher Rajaee[2]

1. Ph.D. Candidate in Civil Engineering, Water and Hydraulic Structures, University of Qom, Iran
2. Professor, Department of Civil Engineering, University of Qom, Iran

Corresponding author: *b.beiranvand@stu.qom.ac.ir*

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ABSTRACT

The implementation of large dam construction projects, despite the positive economic and social effects on the region, may endanger the development of the region with long-term negative effects. Therefore, it seems necessary to pay attention to this issue to reduce the negative effects of large dam construction projects and to consider them in the evaluation of benefits and costs for policy and codified planning in the water resources sector. In this research, Shannon's entropy-TOPSIS methodology and fuzzy TOPSIS methods have been used to identify and prioritize the environmental risk of Eyvashan dam in the construction and operation phases. Also, in this article, to improve the risk management of earthen dams, a comprehensive review was presented to overcome the disadvantages of traditional FMEA through the improvement of FMEA, with the combination of Fuzzy Inference System (FIS). The results show that in both Shannon's entropy-TOPSIS and fuzzy TOPSIS methods, soil erosion in the construction phase and aquatic in the exploitation phase is the major environmental risks. Evaluation of Risk Priority Number (RPN) in both traditional RPN and FIS-RPN modes shows a significant increase in RPN in fuzzy mode compared to the traditional method in all risk environments. Therefore, the urgency of action evaluation criteria in the FIS-FMEA mode is much more serious than in the traditional FMEA mode and requires more accurate identification and monitoring of risk environments.

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1. Introduction

The negative signs of climate change and atmospheric hazards (earthquakes, floods, droughts, etc.), which appeared significantly in the world two decades ago, have now entered an acute and critical phase. Due to the direct impact of climate change on major water projects, including dam construction, human life is seriously threatened. On the other hand, there is always a weakness in predicting the trends and possible effects of climate change and the risks associated with it. Therefore, new methods, techniques, and tools have been designed and presented to care for, monitor, control, eliminate or minimize the risks to humans in the environment. The construction of dams and irrigation and drainage networks, along with all the positive effects, also has negative effects, so attention to environmental hazards must be considered. Nowadays, the analysis and study of the hazards caused by the construction of the dam have received more and more attention from researchers. Environmental activists have warned that the construction of dams on a number of the world's major rivers has endangered the natural environment and wildlife in these waters [1]. Of course, dams also have many advantages and can offer dependable water resources, safeguard surrounding areas from flooding, and produce clean energy [2]. Beck et al. (2012) by examining the environmental and livelihood effects of dams have emphasized the need to build dams. In their research, they have concluded that the establishment of a dam in the region creates new opportunities for economic development. They also stated that although policies in dam projects are aimed at creating sustainable development, they would have dual environmental consequences [3]. Failure Mode and Effects Analysis (FMEA) is an effective analytical tool for identifying root causes, occurrences, and consequences of potential failures that may occur systematically for the product and process [4]. Ahmadi, et al. (2015) in a study evaluated the uncertainty in environmental risk through bayesian networks of Abu al-Abbas Dam in Bandar Abbas. Based on probability theory, Bayesian networks offer a potent tool for conceptualizing the interaction between variables and uncertainties. In the first stage, they developed a structure based on the interaction of variables using a graphical model. The relationships between various variables were then modeled, and the input variables into the Bayesian network that affect the risk index and outcome index, two categories of risk, were identified. Finally, a fresh fuzzy set analysis produced probability values for risk levels. The outcomes demonstrated that the Abu al-Abbas Dam's environmental risk is regarded as being at a high level, with a probability of 12.8%. They also used risk sensitivity analysis to find the most effective environmental hazard variables at the dam site [5]. In the results of his study, practical plans for reducing and controlling risk were presented. Malekmohammadi, et al (2018) introduced environmental risk assessment as a common and effective tool to reduce the negative effects of risk factors. They used the Bayesian network (BN) model, which is based on the impact diagram's (ID) hierarchical structure of variables, to analyze ERA in their study. Additionally, the main environmental risk factors in the area have been identified based on the Delphi method and particular features of the study area. These included floods, water pollution, earthquakes, land-use change, erosion, sedimentation, and population impact [6]. Shaffiee Haghshenas, et al (2016) in a study to identify project risks used the experiences and opinions of experts, including think tanks and consulting meetings. Risk rating was also done using the fuzzy TOPSIS method [7]. According to their results, the design error with the highest level of risk and the earthquake with the lowest level of risk were obtained for Alaviyan Dam Ghorbanalipour et al (2018) used a questionnaire to first identify the project's primary risks. They then identified solutions to address the most pressing risks, and finally, using a decision model, they selected the best option for the Polrood dam project's most crucial environmental risk factors through pairwise comparisons [8]. Naderpour et al. (2018) in a study investigated environmental assessment using neural networks [9]. At various project stages, risk parameters were identified and ranked to assess the risk in the dam. Additionally, 16 subsets of risk factors across four categories physical and chemical, economic, social and cultural, biological, safety and health were assessed and ranked using the DEMATEL-ANP method. The human risk of the Panchet dam was evaluated by Bid and Siddique in 2019 [10]. To address issues like flood control, drinking and industrial water supply, electricity generation, and other issues, the Panchet dam along the Damodar River at the border of West Bengal and Jharkhand states of India was put into operation in 1959. But now, due to rapid sedimentation and reduced water storage capacity, it has become a threat to those around it. Therefore, assessing the human risk of the dam is very important. Initially, 9 dam human risk options were identified using the Delphi questionnaire and ranked using TOPSIS and WASPAS. To resolve the differences between the results of the two methods, the method of merging the mean rank has been used. Finally, the option of population relocation was recognized as the most dangerous risk. Darvishi, et al (2020) calculated the priority risk number (RPN) for each environmental risk factor using the EFMEA method. In the next step, the identified risks were ranked based on RPN values. The risk of Balarood River pollution with 125 RPN is a priority, according to a comparison of RPN values. The severity, probability, and extent of pollution were used to calculate the entropy values for the environmental hazards identified in the follow-up phase. To assess and prioritize potential environmental hazards, the VIKOR method was used as one of the multi-criteria decision-making techniques [11]. Jafari et al. (2020), used a combined wavelet-genetic programming (WGP) method to improve the prediction of BOD run. They used Shannon's entropy to identify optimal WGP input combinations. The results of their studies showed that the use of Shannon's entropy is suitable for determining the optimal combination of inputs of machine learning methods. Also, the comparison of the results shows that the WGP model is superior to the GP, ANN, DT, BN, and WANN models based on the data of the Varian Hotel and Dam Input stations [12]. Huang et al. (2019), for instance, used an extended TODIM method to determine the priority ranking of the individuated failure modes and probabilistic linguistic term sets to handle the ambiguity that existed in the risk assessment of FMEA [13]. To assess the risk of the Amir Kabir Dam, in Iran, Ardeshirtanha and Sharafati (2020) presented a stochastic method based on failure modes and effects and Monte Carlo simulation. This method involved computing the RPNs of failure modes using a modified stochastic FMEA that took into account weighted risk factors and the opinions of experts [14]. Roberto Ribas et al. (2021) had studies evaluating FMEA for different failure modes in earth dams [15]. Using the fuzzy logic method combined with a traditional technique, such as FMEA, has been very effective in assessing the asset risk of large projects [16]. In a review study, Wang et al. (2022) In order to promote the practical application of dam risk management in cascading reservoirs, conducted extensive research to clarify the focus of future studies [17]. In this research, by understanding the positive effects of dam construction, an attempt has been made to identify, evaluate and manage the environmental risks of Eyvashan dam in the construction and operation phases Using Shannon's Entropy-

TOPSIS Methodology and Fuzzy FMEA. Also, to improve the risk management of dams, the performance of traditional- FMEA and FIS -FMEA methods was compared.

2. Materials and methods

2.1. Survey of the study dam area

To make maximum use of the Horrood River and supply the required water to the lands of Eyvashan and Chaghalvandi plains, the construction of Eyvashan dam on Horrood River in Khorramabad city was proposed. These lands, which are located on the left and right banks of the Horrood River, include about 5,000 ha of rainfed lands without any development restrictions. In addition to the lack of water, the existing Chaghalvandi network is also supplied through the Eyvashan dam. With the construction of Eyvashan dam and related facilities, it is possible to save a part of the basic discharge that could not be used as a natural flow in the downstream lands (in unnecessary months) and especially during the Horrood River floods. In fact, due to the rainfed lands of the region, the lack of storage reservoirs to regulate winter and spring flows, groundwater shortages, and increasing water needs in the region, the water needs of most of the downstream lands are met by constructing Eyvashan dam. The dam is located 1.5 km upstream of Eyvashan Golestan village and about 57 km from Khorramabad city, on Horrood River. The catchment area of the Horrood River up to the axis of the Eyvashan dam is 120 km2. The dam is of earth-rockfill type with a vertical clay core, the height of which is 62 m from the bed (1804 masl), the crest level of the dam is 1868 masl and the normal operating level is 1864 masl. The volume of the reservoir at the normal level of operation of the dam is 52 MCM and the area of the lake at the normal level is 2.3 km2. Fig. 1 shows the location of the Eyvashan dam.

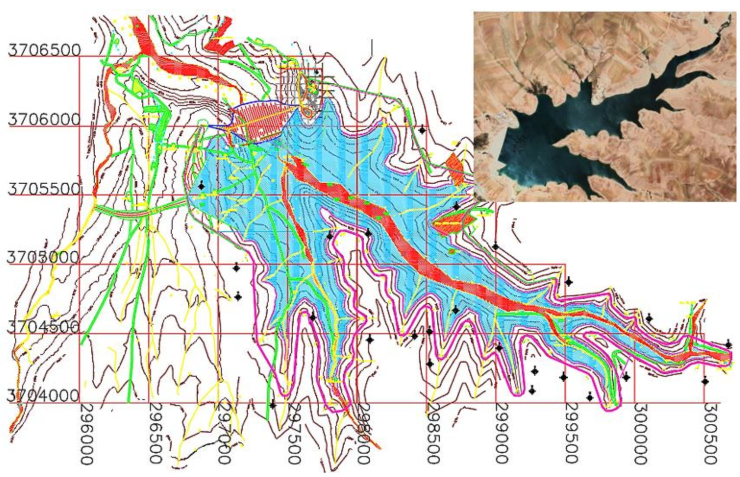

Fig. 1. Location of Eyvashan dam.

2.2. Study Method

2.2.1. Ranking risks using the TOPSIS method

To rank the environmental risks of Eyvashan dam using TOPSIS method, first using Shannon entropy method, all the considered indices were weighted, and then using TOPSIS model, which is one of the multi-criteria decision models, was prioritized.

2.2.1.1. Shannon entropy method

In the social sciences, physics, and information theory, entropy is a crucial concept. One technique for multi-criteria decision-making methods is Shannon entropy. According to the entropy method, an index is more significant the more widely distributed its values are. These are the steps in this approach:

Step 1: P_{ij} is calculated using Equation (1):

$$P_{ij} = \frac{a_{ij}}{\sum_{i=1}^{m} a_{ij}} \quad (1)$$

Step 2: The entropy value E_j (confidence value) is calculated using Equation (2):

$$E_j = -k \sum_{i=1}^{m} \left[P_{ij} ln P_{ij}\right], \qquad k = \frac{1}{\ln(m)} \quad (2)$$

Step 3: The value of d_j (uncertainty value) is calculated using Equation (3):

$$d_j = 1 - E_j \quad (3)$$

Step 4: The value of W_j or the value of weights is obtained using Equation (4):

$$W_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \quad (4)$$

2.2.1.2. Steps of TOPSIS and fuzzy TOPSIS methods

One of the best multi-criteria decision models is the TOPSIS model, which was proposed by Hwang and Yoon in 1981. This method is based on the concept that the selected option should have the shortest distance from the positive ideal solution (best possible state) and the greatest distance from the negative ideal solution (worst possible case). These are the procedures for using this approach:

2.2.1.3. TOPSIS

Step 1: Create an evaluation matrix consisting of m alternatives and n criteria

$$\mathrm{A_{ij}} = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{bmatrix} \quad (5)$$

Step 2: The matrix is normalised using the normalisation method to form the matrix

$$\mathrm{n_{ij}} = \frac{a_{ij}}{\sum_{i=1}^{m} (a_{ij})^2} \quad (6)$$

Step 3: Calculate the weighted normalised decision matrix

$$V = N \times \mathrm{W_{n\times n}} \quad (7)$$

Step 4: Determine the worst alternative (V_j^+) and the best alternative (V_j^-):

In selecting the ideals in this plan, all three indicators of risk severity, risk occurrence, and risk detection have a negative aspect. Therefore, according to this model, the best values for the negative index are the smallest number in the matrix and the worst values for the negative index are the largest number in the matrix.

Step 5: Calculate the distance of each option between the V_j^+ and the V_j^-

$$d_i^+ = \sqrt{\sum_{j=1}^{n}\left(V_{ij} - V_j^+\right)^2} \qquad i=1, 2, \ldots, m \tag{8}$$

$$d_i^- = \sqrt{\sum_{j=1}^{n}\left(V_{ij} - V_j^-\right)^2} \qquad i=1, 2, \ldots, m \tag{9}$$

Step 6: Determine the relative proximity of an option to the ideal solution (C_i)

$$C_i = \frac{d_i^-}{d_i^- + d_i^+} \tag{10}$$

Step 7: Rank the alternatives according to (C_i)

The fuzzy TOPSIS method was first introduced in 1992 by Chen and Huang. In this method, to solve the shortcomings of the classical method, the elements of the decision matrix or the weight of the criteria, or both, were evaluated by the linguistic variables represented by fuzzy numbers. Different methods can be used to perform operations in fuzzy TOPSIS method. The type of fuzzy number used, the normalization method and the ranking method vary between the various models of this approach. To perform calculations of the fuzzy TOPSIS technique, a suitable linguistic spectrum must first be used to collect the data. The following are the steps of this method:

2.2.1.4. Fuzzy TOPSIS

Step1: Decision matrix formation: First, a fuzzy decision matrix is created that has a row of columns and several columns, and the numbers inside the matrix are the scores that experts give to the options in different criteria. In this matrix, Ai represents the i-th option, Cj represents the j-th index, and Xij represents the performance of the Ai option according to the Cj index.

$$\widetilde{D} = \begin{array}{c} \quad C_1 \quad \cdots \quad C_n \\ \left[\begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix}\right] \end{array} \qquad \widetilde{x_{ij}} = \left(a_{ij}, b_{ij}, c_{ij}\right) \tag{11}$$

Step 2: Normalizing the fuzzy decision matrix: The scales of the scaleless decision matrix for the positive and negative criteria are calculated from the following equations, respectively:

$$\widetilde{r_{ij}} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right) \qquad \text{and} \quad C_j^* = \max C_{ij} \quad \text{(benefit criteria)} \tag{12}$$

$$\widetilde{r_{ij}} = \left(\frac{\bar{a}_j}{a_{ij}}, \frac{\bar{a}_j}{b_{ij}}, \frac{\bar{a}_j}{c_{ij}}\right) \qquad \text{and} \quad a_j^- = \min a_{ij} \quad \text{(cost criteria)} \tag{13}$$

Step 3: Matrix weighting: By multiplying the significance coefficient of each criterion in the dimensionless matrix, the decision matrix becomes fuzzy.

$$\widetilde{v_{ij}} = \left(\widetilde{r_{ij}}(.)\widetilde{w_j}\right) \qquad \widetilde{w_j} = (\widetilde{w_1}, \widetilde{w_2}, \dots, \widetilde{w_n}) \tag{14}$$

Step 4: Determine the worst alternative (V_j^+) and the best alternative (V_j^-):

$$A^- = \left(\widetilde{V_1^-}, \widetilde{V_2^-}, \dots, \widetilde{V_n^-}\right) \quad \text{where } \widetilde{V^-} = \min\{V_{ij}\}, \; i - 1,2,\dots,m \text{ and } j = 1,2,\dots,n \tag{15}$$

Step 5: Calculate the distance of each option between the V_j^+ and the V_j^-

$$d_i^+ = \sum_{j=1}^{n} d_v\left(\widetilde{V_{ij}}, \widetilde{V_j^+}\right), \quad i = 1,2,\dots,m \tag{16}$$

$$d_i^- = \sum_{j=1}^{n} d_v\left(\widetilde{V_{ij}}, \widetilde{V_j^-}\right), \quad i = 1,2,\dots,m \tag{17}$$

$$d = \sqrt{\frac{1}{3}} \times ((a - v_1)^2 + (b - v_2)^2 + (c - v_3)^2) \tag{18}$$

Step 6: Determine the relative proximity of an option to the ideal solution (C_i)

$$C_i = \frac{d_i^-}{d_i^- + d_i^+} \qquad i = 1,2,\dots,m \tag{19}$$

Step 7: Rank the alternatives according to (C_i)

At this stage, the options are ranked based on the similarity index obtained, and options with a higher similarity index are preferred.

2.2.2. FIS-FMEA

Risk management and increasing the reliability of construction projects, especially dam construction, are among the important issues that are very important from the design phase to implementation and even after construction. FMEA is one of the most powerful methods in this field, which makes high performance and good analysis one of the most important risk analysis techniques and strengthens the safety of systems. It is worth noting that the Traditional FMEA approach emphasizes over-precision and considers all factors with certainty, and therefore is not very compatible with complex systems and the real world. Therefore, we should seek to build models that consider ambiguity as part of the system. Accordingly, Fuzzy FMEA replaced Traditional FMEA to provide a practical approach to the fuzzy inference system and predict the risk of environmental failure occurrence. To eliminate the shortcomings of the Traditional FMEA method in not considering the weight of factors, input parameters, and certainty of experts, the Fuzzy FMEA model was replaced by predicting environmental failure risk using a fuzzy inference system that also considers the weight of the parameters. In both methods, the three factors of severity, probability of occurrence, and probability of detection according to Equation (20) must be multiplied to obtain the RPN number. This number is an indicator for prioritizing potential failure modes, ie RPN The different failure modes are compared for prioritization.

$$Risk\ Priority\ Number\ (RPN) = S \times O \times D \tag{20}$$

By storing its fundamental parts in a legal basis and database and using fuzzy inference to determine the final output value, a fuzzy inference system (FIS) can draw on the human experience. If-then rules govern fuzzy inference. The system under consideration's prior knowledge has a significant impact on how the if-then rules and related membership functions are altered. The knowledge experience of human experts cannot, however, be systematically converted into the knowledge base of a fuzzy inference system (FIS). Additionally, to produce outputs with the required error rate, algorithms must be adapted or learned. To put it another way, the artificial neural network learning process does not rely on the expertise of human experts. It is not possible to encode prior knowledge in an artificial neural network because prior knowledge is typically acquired from human experts and is best expressed as a fuzzy set of rules.
Sentences can be multivariate and are in the "then" section of fuzzy inference systems, while hypotheses are in the "if" section. The Mamdani method was used in this study to develop a fuzzy inference system (FIS) risk assessment [18]. This model is being used because the output values are fuzzy sets, which are frequently used to represent expert knowledge. Furthermore, it is preferable to characterize the expertise intuitively and in a more human-like manner as opposed to other methods, like the Tsukamoto FIS and the Sugeno fuzzy model, whose output values are linear or constant. In addition, the FIS-FMEA method has made use of 180 rules. Tables 1 to 3 shows linguistic variables and corresponding fuzzy numbers for failure severity, failure occurrence, and detection power [19].

Table1
Qualitative approach for the OCC.

Level	Probability of the Failure	Occurrence	Description	Score
O1	P<0.001	Extremely unlikely	Unexpected breakdowns and rare breakdown	1
O2	0.001≤P<0.01	Remote	The number of breakdown events is low	2
O3	0.01≤P<0. 1	Occasional	The number of breakdown events is average	4
O4	0.1≤P<0. 2	Reasonably likely	The number of breakdown events is high	7
O5	P≥0.2	Frequent	Breakdowns almost always happen	10

Table 2
Qualitative approach for the levels of SEV of the hazard impact.

Level	Population	Environment	Economic	Description	Score
S1	No injures	No measurable impact	Small (<$ 0.01M)	Ineffective	1
S2	First aid	Minor impact on habitat	Medium ($0.01–0.1M)	Low impact on project performance	2
S3	Few injures	Moderate/ local reversible	Medium ($0. 1–1M)	Moderate effect on project performance with minor damage	4
S4	Injuries/disabilities	Significant/ large reversible	High ($1–10M)	High impact on project performance with equipment damage	6
S5	Few casualties	Significant/ local irreversible	Very high ($10–100M)	Serious effect - When a fault affects the project safety system and warns that the project will stop.	9
S6	Many casualties	Catastrophic/ irreversible/ large	Massive (>$100M)	Dangerous effect - When a fault affects the project's safety system and is unannounced	10

Table 3
Qualitative approach for the DET.

Level	Detection	Description	Score
D1	Detectable	The type of failure, its origin, and its effects are all identified by design review.	1
D2	High	The likelihood is high that the failure type, its root cause, and its effects will all be revealed by the design review.	3
D3	Moderate	A design review has a marginal chance of determining the kind of failure, its root cause, and its effects.	5
D4	Low	A design review has little chance of identifying the kind of failure, the reason it occurred, and its effects.	7
D5	Very Low	A design review is very unlikely to pinpoint the kind of failure, the reason for the failure, and the failure's effects.	9
D6	Undetectable	Design reviews are unable to pinpoint the nature of a failure, its root cause, or its effects.	10

Different methods have been developed for evaluating FMEA and there may be differences in the views of each member of the FMEA team depending on the type of expertise, skills, background, and types of ambiguities such as inaccuracy, ambiguity, and incompleteness of opinions. Although Fuzzy FMEA can identify the risk of effects identified in the environmental assessment of dam construction, to address its shortcomings, the Modified fuzzy FMEA method was used on a case-by-case basis to assess the environmental risk of the Eyvashan dam during construction and operation. The method of scoring steps and fuzzy inference system in the construction phase and operation of Eyvashan dam begins with a subjective evaluation of the ranking based on three indicators of severity, probability of occurrence, and risk detection in the form of a questionnaire by experts. In fact, the proposed method turns linguistic terms into ambiguous numbers by using triangular membership functions (TMFs) and trapezoidal membership functions (TRMFs). Then, using a fuzzy rule, a two-step expert system is built in which conditional sentences are made up of a combination of linguistic terms and logical operators. These two steps include the inference step. Membership functions are shown in Fig. 2. The FIS-RPN indices are shown in Table 4. For RCI defuzzification, the centroid method is applied. The aggregated geometric representation defines a polygon with equal upper and lower sub-areas that are separated by a horizontal line, and the defuzzified or crisp RCI value is calculated by determining the lower subarea's center of gravity.

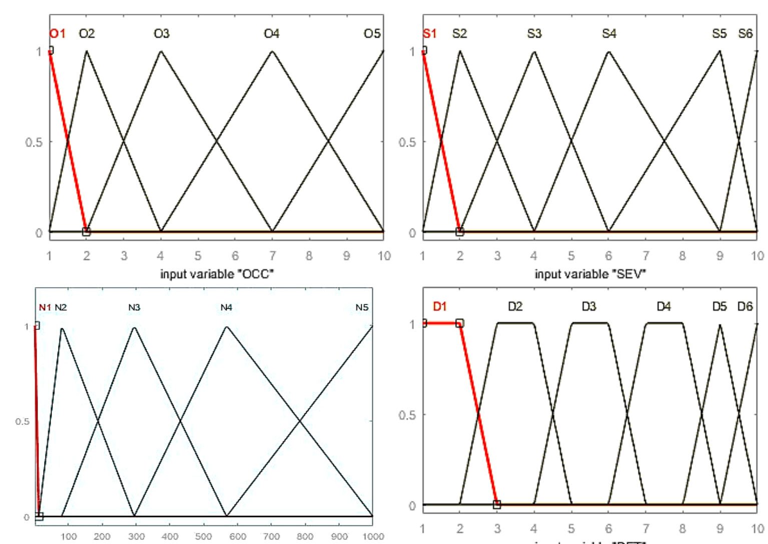

Fig. 2. FIS-FMEA membership functions.

Table 4
The urgency of action evaluation criteria.

Category	Urgency	Meaning of urgency of action	FIS-RPN
N1	Immediate	Executive activities do not endanger the continuation of the project	567-1000
N2	High	Risks are likely to increase but not a threat to the project	294-567
N3	Medium	There is a chance of risk in executive activities and it needs to be considered.	80-294
N4	Medium Low	The risks are high and Inspection and prevention should be continuous	12-80
N5	Low	The risks are very serious and executive activities need to be reviewed	1-12

The FIS- FMEA procedure is summarized as follows (Fig. 3).

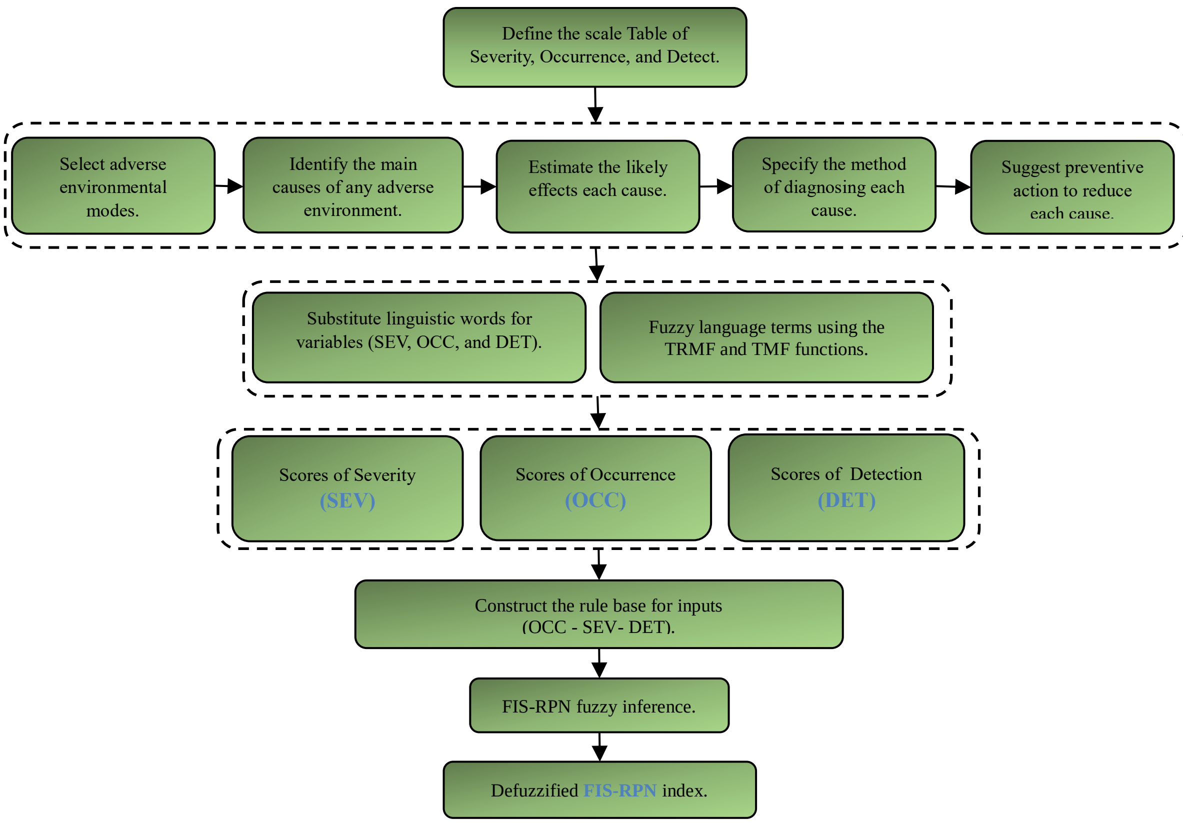

Fig. 3. Steps of risk assessment of FIS-FMEA method.

2.3. Environmental risks of Eyvashan dam in construction and operation phase

As mentioned, a questionnaire was used to prioritize the factors that could potentially generate risk. According to this method, questionnaires were used by 5 experts familiar with this design and environment to complete the questionnaires. To complete the questionnaire, experts in the field of dam construction, including environmental engineers (EE), civil engineers (CE), health and safety expert (HS), legal and social experts (LS), and project managers of consulting engineers (PM) have been used. Pearson, Cronbach's Alpha, and Kuder- Richardson reliability coefficients in SPSS software were used to determine the correlation coefficient of the questionnaire results which were evaluated by experts. At the top of the triangle, the results of all three correlation coefficients are given, and at the bottom of the triangle, the best evaluation is presented (Table 5).

Table 5
Correlation coefficients of expert risk assessment.

Correlation coefficient		EE	CE	HS	LS	PM
EE	Pearson		0.965	0.895	0.901	0.923
	Kuder-Richardson		0.905	0.838	0.808	0.827
	Cronbach's Alpha		0.919	0.879	0.850	0.853
CE	Pearson	0.965		0.854	0.863	0.876
	Kuder-Richardson			0.761	0.732	0.760
	Cronbach's Alpha			0.817	0.789	0.801
HS	Pearson	0.895	0.854		0.840	0.811
	Kuder-Richardson				0.739	0.694
	Cronbach's Alpha				0.818	0.753
LS	Pearson	0.901	0.863	0.840		0.839
	Kuder-Richardson					0.662
	Cronbach's Alpha					0.731
PM	Pearson	0.923	0.876	0.811	0.839	
	Kuder-Richardson					
	Cronbach's Alpha					

Environmental Engineer (EE), Civil Engineer (CE), Health and Safety expert (HS), Legal and Social expert (LS), and Project Manager of consulting engineers (PM) Among the correlation coefficients studied, Pearson correlation coefficient is the most valid method for analyzing the results of risk assessment of experts. Therefore, by interpreting the results of correlation coefficients, the results of risk assessment of the expert questionnaire can be trusted. After analyzing the questionnaires, their geometric mean was considered for each of the environmental activities. By studying and evaluating the environmental impact of Eyvashan dam, 27 risks were identified in each of the construction and operation phases. The identified risks are related to Biologically, Economic-Social, Physico-Chemical, Cultural, and Strategic environments.

3. Results and discussion

3.1. Results of fuzzy TOPSIS method

After identifying the environmental risks of Eyvashan dam and scoring these risks based on risk severity indicators, the probability of occurrence, and the importance of risk detection by experts, the average of each indicator for each risk in the Excel software environment was obtained. To rank the environmental risks using the TOPSIS method, first, the considered indices were weighed according to relations 1 to 4 according to the Shannon entropy method and the results are given in Table 6 in the construction and operation phases, then according to the steps of the TOPSIS method. The value of Ci was obtained for each risk (Fig. 4).

Table 6
Weights obtained from entropy method in construction and operation phase.

Indicator Indicator weight	Severity (W_1)	Occurrence (W_2)	Detection (W_3)
Construction phase	0.33	0.39	0.28
Operation phase	0.34	0.33	0.33

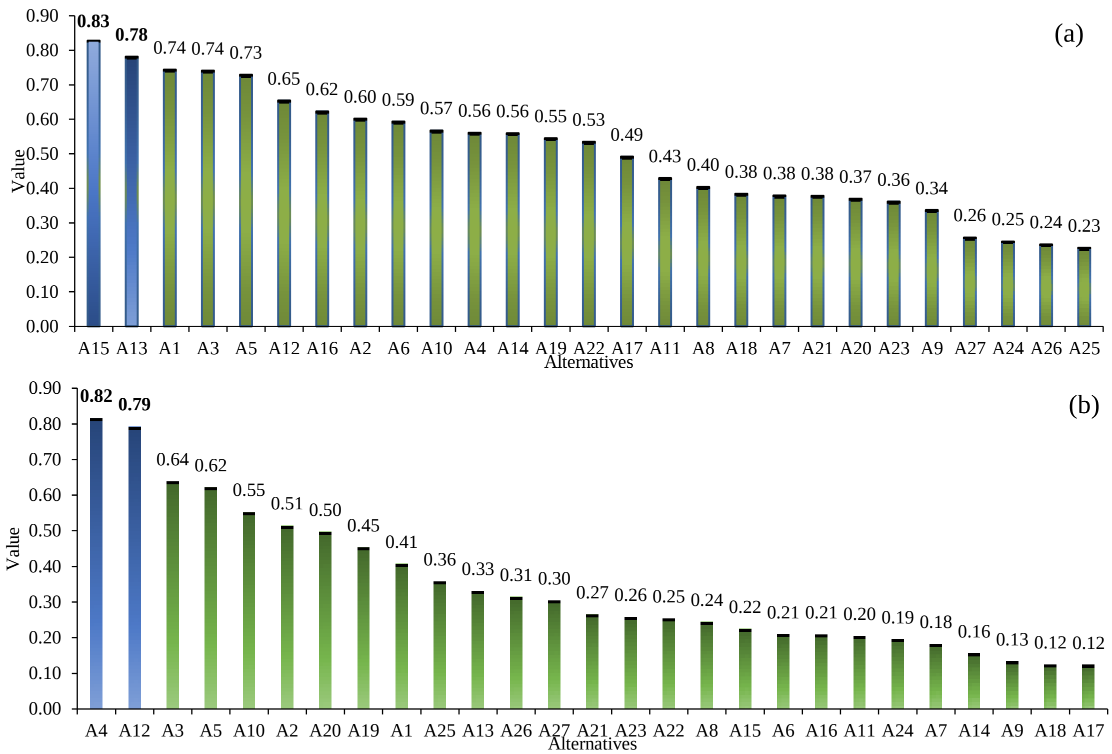

Fig. 4. Prioritization of environmental risks of Eyvashan dam using TOPSIS model a) Construction phase, b) Operation phase.

3.2. Results of fuzzy FIS-FMEA method

The FIS-FMEA model was implemented in MATLAB software. The inputs in the FIS-FMEA method include OCC, SEV, and DET and the output. Fig. 5 shows the relationship between OCC, SEV, and DET in the FIS-FMEA method in two dimensions and three dimensions.

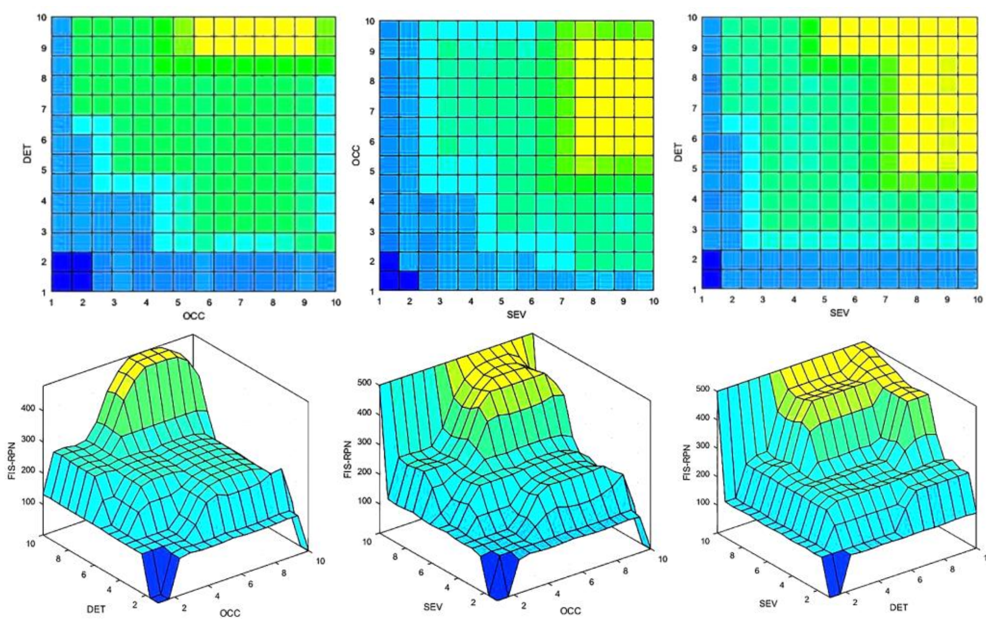

Fig. 5. 2D and 3D Input/output level graph FIS-FMEA method.

Fig. 5 clearly shows the ratio of different input and output changes. The results of traditional RPN and FIS-RPN methods in the two phases of construction and operation of Eyvashan dam are shown in Tables 7 and 8.

Table 7
Summary of the results of expert risk assessment in the construction phase.

Risk assessment variables	Activities and risks		Construction of access road Workshop camp and residential building Excavation and embankment	Land leveling Infrastructure (water, electricity, gas, etc.) Waste Depot	Extraction of soil materials from sources Machinery and equipment activity Redirect the river	Storage of petroleum and fuel materials and blasting materials Reservoir cleaning Explosion	Manpower activity in the workshop (work at height, in tunnels and valleys, etc.) Fishing and boating Construction of dam and technical buildings (structures)
	Symbol	Environmental risks	Occurrence (OCC)	Severity (SEV)	Detection (DET)	RPN	FIS-RPN
Biologically	A1	Rare species	5	4.94	5.22	129	260
	A2	Plant cover	3.7	4.5	4.67	78	221
	A3	Habitat	4.6	5.17	5.5	129	276
	A4	Aquatic	3.3	9.06	3.61	107	283
	A5	Animal species	4.6	5.11	5.28	123	272
Economic and social	A6	Agriculture	3.2	8	4.44	115	277
	A7	Livestock	2	6.89	3.89	54	132
	A8	Property value	2.7	6.11	3.11	52	155
	A9	Healthcare	2.4	7.78	2.22	41	213
	A10	diseases	3.9	4.83	3.56	68	135
	A11	Cultural Heritage	2.6	5.83	3.78	58	133
Physical and chemical	A12	water pollution	3.3	7.22	5.44	131	282
	A13	Soil pollution	4.6	5.5	6.44	161	294
	A14	Air and noise pollution	3.3	5.17	4.61	78	276
	A15	Soil erosion	4.7	6.5	6.17	189	417
	A16	Destruction of downstream lands	3.3	7.17	4.89	117	283
	A17	Destruction of pastures	2.9	6.67	3.94	76	228
	A18	Groundwater quality	1.3	9	4.33	50	234
	A19	River water quality	2.6	7.56	5.28	102	268
	A20	Sedimentation of the dam reservoir	1.3	9.56	3.83	49	138
Cultural	A21	Migration	2.4	5.06	3.61	44	136
	A22	Tourism	3.1	4.44	4.89	66	228
	A23	population	2.3	4.83	3.61	40	135
Strategic	A24	Safety and security (terrorism and sabotage)	1.1	9.22	1.89	17	114
	A25	Damage potential and downstream danger of the dam	1.1	8.78	1.83	16	110
	A26	Earthquake vulnerability	1.1	9.56	1.06	10	125
	A27	Flood	1.1	9.56	1.83	18	125

As shown in Table 7, FIS-RPN values show significant growth compared to traditional RPN. An example of the results of the rules applied to A15 is also shown in Fig. 6.

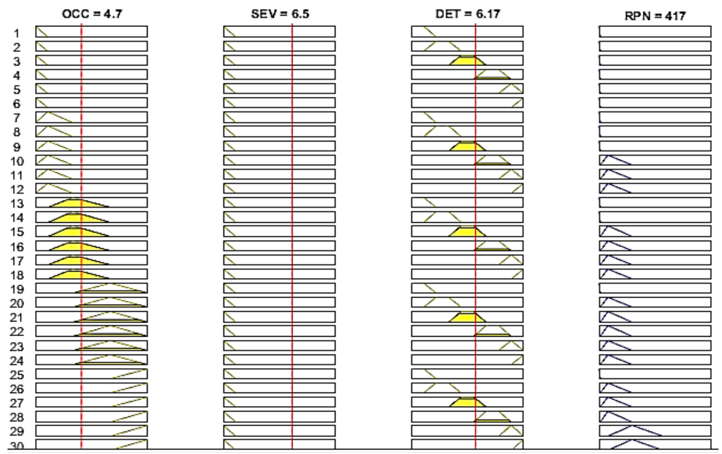

Fig. 6. Results of rules fuzzy interface system for environmental risk (A15) in the construction phase.

As can be seen in Fig. 6, to assess the risk of soil erosion in the construction phase of Eyvashan dam by applying input OCC = 4.7, SEV= 6.5, and DET = 6.17, output FIS-RPN = 417. The results of other risks A1 to A27 (Table 7) are similar to Fig. 6.

Table 8
Summary of the results of expert risk assessment in the FIS in the operation phase.

Risk assessment variables	Activities and risks						
			Resettlement; Impounding of the dam reservoir	Rapid drawdown during floods; Thermal stratification; River flow regulation (downstream water supply)	Eutrophication; Operation camp (manpower activity in the dam); Operation of roads and bridges	Sediment and erosion; Dredging; Fisheries and fish farming	Tourism development; Earthquake or induced earthquake; land-use change
	Symbol	Environmental risks	Occurrence (OCC)	Severity (SEV)	Detection (DET)	RPN	FIS-RPN
Biologically	A1	Rare species	1.89	4.39	6.28	52	210
	A2	Plant cover	2.50	4.44	6.06	67	215
	A3	Habitat	2.94	4.89	6.28	90	260
	A4	Aquatic	4.11	6.11	5.28	133	342
	A5	Animal species	2.89	4.83	6.22	87	255
Economic and social	A6	Agriculture	1.44	3.11	6.17	28	129
	A7	Livestock	1.28	2.94	6.50	24	130
	A8	Property value	1.50	3.22	6.72	32	132
	A9	Healthcare	1.11	2.56	6.56	19	129
	A10	Diseases	2.83	4.39	5.17	64	219
	A11	Cultural Heritage	1.67	2.61	6.28	27	129
Physical and chemical	A12	Water pollution	3.72	5.61	5.67	118	298
	A13	Soil pollution	1.94	3.50	6.22	42	130
	A14	Air and noise pollution	1.28	2.61	6.61	22	129
	A15	Soil erosion	1.44	3.28	6.06	29	130
	A16	Destruction of downstream lands	1.56	2.67	6.83	28	132
	A17	Destruction of pastures	1.11	2.17	6.78	16	128
	A18	Groundwater quality	1.06	2	6.89	15	127
	A19	River water quality	2.56	3.72	5.61	53	132
	A20	Sedimentation of the dam reservoir	2.67	3.78	6.67	67	239
Cultu ral	A21	Migration	1.67	2.94	7.33	36	136
	A22	Tourism	1.56	3	7.33	34	137
	A23	Population	1.44	3.22	7.33	34	135
Strategic	A24	Safety and security (terrorism and sabotage)	1.10	2.22	8.06	18	129
	A25	Damage potential and downstream danger of the dam	2	3.22	7.89	51	137
	A26	Earthquake vulnerability	1.61	3.39	7.94	43	134
	A27	Flood	1.78	2.94	7.94	42	136

Table 8 also shows the significant growth of FIS-RPN values compared to traditional RPN. In general, in the FIS-RPN method, higher results have been obtained in both construction and operation stages, which can be due to the application of weights for different environments in the fuzzy method. Also, there is a big difference in the results of FIS-RPN and traditional RPN methods in the two stages of construction and operation of Eyvashan dam. This is due to the completion of the installation of precision instruments such as electrical piezometer foundation & embankment, total pressure cell, standpipe piezometer, inclinometer & settlement, accelerometers, hygrometer, hydromechanical equipment, meteorological stations, microgeodesy pillars, and other dam monitoring equipment in the operation phase. It can also be due to differences in the type of risks and hazards in dam construction activities. Identifying potential hazards in the operation phase is easier and more recognizable than in the construction phase of the dam. This is because the DET values set by experts in the operation phase are much higher than in the dam construction phase. In the proposed method, DET values will have a more special role due to the importance of inspection and monitoring of activities Tables 9 and 10 show a general comparison between the FIS-RPN and traditional RPN results.

Table 9
Comparison of the results of environmental risks of Eyvashan dam in construction operation phases according to traditional RPN and FIS-RPN methods.

Symbol	Environmental risks	traditional RPN	Category	Symbol	Environmental risks	FIS-RPN	Category
A15	Soil erosion	189	N3	A15	Soil erosion	417	N2
A13	Soil pollution	161	N3	A13	Soil pollution	294	N2
A12	Water pollution	131	N3	A4	Aquatic	283	N3
A1	Rare species	129	N3	A16	Destruction of downstream lands	283	N3
A3	Habitat	129	N3	A12	Water pollution	282	N3
A5	Animal species	123	N3	A6	Agriculture	277	N3
A16	Destruction of downstream lands	117	N3	A3	Habitat	276	N3
A6	Agriculture	115	N3	A14	Air and noise pollution	276	N3
A4	Aquatic	107	N3	A5	Animal species	272	N3
A19	River water quality	102	N3	A19	River water quality	268	N3
A2	Plant cover	78	N4	A1	Rare species	260	N3
A14	Air and noise pollution	78	N4	A18	Groundwater quality	234	N3
A17	Destruction of pastures	76	N4	A17	Destruction of pastures	228	N3
A10	Diseases	68	N4	A22	Tourism	228	N3
A22	Tourism	66	N4	A2	Plant cover	221	N3
A11	Cultural Heritage	58	N4	A9	Healthcare	213	N3
A7	Livestock	54	N4	A8	Property value	155	N3
A8	Property value	52	N4	A20	Sedimentation of the dam reservoir	138	N3
A18	Groundwater quality	50	N4	A21	Migration	136	N3
A20	Sedimentation of the dam reservoir	49	N4	A10	Diseases	135	N3
A21	Migration	44	N4	A23	Population	135	N3
A9	Healthcare	41	N4	A11	Cultural Heritage	133	N3
A23	Population	40	N4	A7	Livestock	132	N3
A27	Flood	18	N4	A26	Earthquake vulnerability	125	N3
A24	Safety and security (terrorism and sabotage)	17	N4	A27	Flood	125	N3
A25	Damage potential and downstream danger of the dam	16	N4	A24	Safety and security (terrorism and sabotage)	114	N3
A26	Earthquake vulnerability	10	N5	A25	Damage potential and downstream danger of the dam	110	N3

Table 10
Comparison of the results of environmental risks of Eyvashan dam in operation phases according to traditional RPN and FIS-RPN methods.

Symbol	Environmental risks	traditional RPN	Category	Symbol	Environmental risks	FIS-RPN	Category
A4	Aquatic	133	N3	A4	Aquatic	342	N2
A12	Water pollution	118	N4	A12	Water pollution	298	N2
A3	Habitat	90	N4	A3	Habitat	260	N3
A5	Animal species	87	N4	A5	Animal species	255	N3
A2	Plant cover	67	N4	A20	Sedimentation of the dam reservoir	239	N3
A20	Sedimentation of the dam reservoir	67	N4	A10	Diseases	219	N3
A10	Diseases	64	N4	A2	Plant cover	215	N3
A19	River water quality	53	N4	A1	Rare species	210	N3
A1	Rare species	52	N4	A22	Tourism	137	N3
A25	Damage potential and downstream danger of the dam	51	N4	A25	Damage potential and downstream danger of the dam	137	N3
A26	Earthquake vulnerability	43	N4	A21	Migration	136	N3
A13	Soil pollution	42	N4	A27	Flood	136	N3
A27	Flood	42	N4	A23	Population	135	N3
A21	Migration	36	N4	A26	Earthquake vulnerability	134	N3
A22	Tourism	34	N4	A8	Property value	132	N3
A23	Population	34	N4	A16	Destruction of downstream lands	132	N3
A8	Property value	32	N4	A19	River water quality	132	N3
A15	Soil erosion	29	N4	A7	Livestock	130	N3
A6	Agriculture	28	N4	A13	Soil pollution	130	N3
A16	Destruction of downstream lands	28	N4	A15	Soil erosion	130	N3
A11	Cultural Heritage	27	N4	A6	Agriculture	129	N3
A7	Livestock	24	N4	A9	Healthcare	129	N3
A14	Air and noise pollution	22	N4	A11	Cultural Heritage	129	N3
A9	Healthcare	19	N4	A14	Air and noise pollution	129	N3
A24	Safety and security (terrorism and sabotage)	18	N4	A24	Safety and security (terrorism and sabotage)	129	N3
A17	Destruction of pastures	16	N4	A17	Destruction of pastures	128	N3
A18	Groundwater quality	15	N4	A18	Groundwater quality	127	N3

The results of Shannon's Entropy-TOPSIS methodology and fuzzy FMEA show that the highest environmental risk in the construction phase of Eyvashan dam belongs to Physico-Chemical, Biologically, Economic-Social, Cultural, and Strategic environments, respectively. Also, the highest environmental risk in the operation phase of Eyvashan dam belongs to Physico-chemical, Biologically, Economic-Social, Strategic, and, Cultural environments respectively. Physical-chemical and biological environments will have the greatest environmental risk in both the construction and operation phases. Also, the results of traditional FMEA and FIS-FMEA evaluations show that the highest RPN in the construction phase is allocated to soil erosion and soil pollution, respectively. However, RPN results in FIS-FMEA method are much higher than traditional FMEA method. Also, results of FIS-RPN survey for the highest scores in the construction phase of Eyvashan dam show that the two modes of soil erosion and soil pollution are in the category N2 (High action). Also, in the fuzzy method, several environments such as Aquatic, Destruction of downstream lands, and Water pollution are very close to N2 category. Also, in the traditional-RPN results, soil erosion and soil pollution are in category N3 (Medium action). Soil erosion and soil pollution are the effects of the Physico-Chemical environment in the construction phase. The results of the traditional-FMEA method are less risky than the FIS-FMEA method. With the construction of the dam, the process of destruction of vegetation and its conversion into agricultural lands, cutting and harvesting of trees and shrubs and livestock grazing has increased, which increases soil erosion and sedimentation in the reservoir of the dam. Also, with the expansion of population centers, development of agricultural lands (entry of pesticides and chemical fertilizers), tourism industry (even during the construction of dams), and other industries, the amount of waste production and soil pollution will increase. Excavation and embankment are important risk factors for soil erosion in Eyvashan dam. In this study, the next priorities of environmental risk of Eyvashan dam in the construction phase with very close scores to aquatic, destruction of downstream lands, water pollution, agriculture, and habitat have been assigned that need special attention. Environmental risk of embankment and excavation operations in the construction phase of the dam, due to the location of the site in the oak macro ecosystem of Iran is of special sensitivity and importance and causes damage to habitats of different species, reducing diversity and density of vegetation. Also, with the entry of batching effluent and crusher into the Horrood River, it is associated with the release of significant volumes of sediments and other contaminants in the water stream, which may stifle fish and juveniles and bury their eggs under mud. The entry of sanitary wastewater into the Horrood River endangers not only the physical and chemical quality of the water but also its biological quality by contaminating the river water.

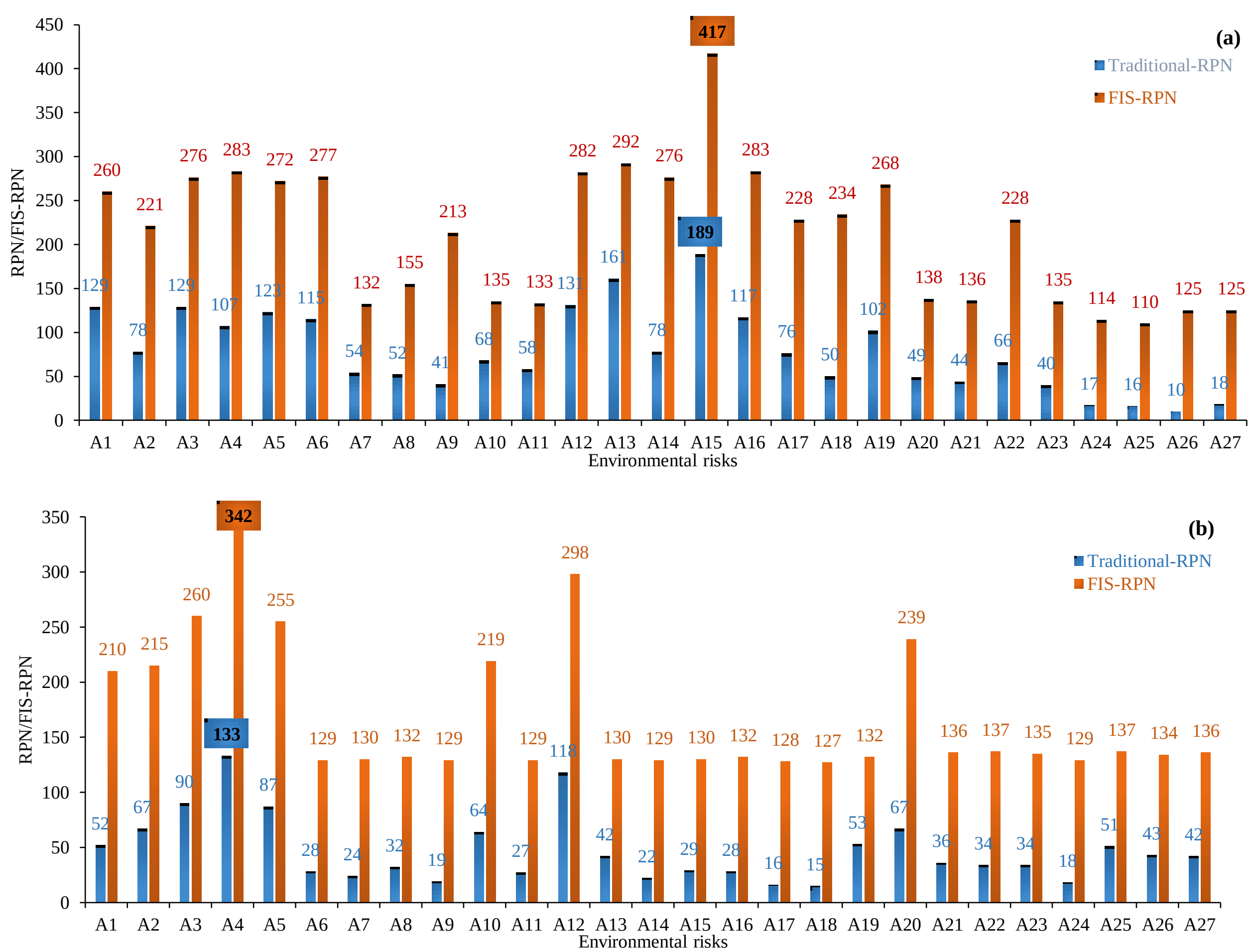

Fig. 7. Comparison of the results of FIS-RPN and traditional-RPN methods, a) Construction phase, b) Operation phase.

Similarly, the results of FIS-RPN survey for the highest scores in the operation phase of Eyvashan dam belong to aquatic and water pollution, which is in N2 category, while in traditional-RPN results, aquatic is in N3 category and water pollution in N4 (Medium-Low) category. Aquatic animals are subsets of the biological environment and water pollution is a subset of Physico-Chemical environment. Aquatic animals include benthos, fish, and other living organisms in the water. Since the riverbed is a suitable place for feeding, reproduction, breeding, hiding, and resting of various aquatic species, especially benthos. In general, the most important feature of a fuzzy inference system is that they have rules that use the opinions of experts. Scores and results of risk assessment in FIS-RPN method are significantly more serious and stricter than traditional-RPN. The results of traditional-RPN method recommend normal performance monitoring, while FIS-RPN method requires much more accurate and serious environmental assessment studies and continuous monitoring of the dam during construction and operation. Fig. 7 shows a comparison of the results of the FIS-RPN and traditional-RPN methods.

4. Conclusion

Assessing and identifying the environmental risk of dams in the construction and operation phases, as well as investigating the causes and consequences of it, helps to provide solutions to reduce the risk of dams. In this research, the traditional-FMEA and FIS-FMEA methods have been used to score different environmental criteria for Eyvashan dam in two phases of construction and operation. Also, the evaluation of environmental risks was investigated by two methods, TOPSIS, and fuzzy TOPSIS, and the ranking of risk environments was determined. The results of prioritizing the risks in both TOPSIS and fuzzy TOPSIS methods are very consistent. Due to the ambiguities and uncertainties in the process of risk factors (SEV, OCC, and DET), fuzzy set theory is proposed to calculate RPN. However, there are shortcomings and ambiguities in the traditional-FMEA decision-making process, leading to normal and unserious results in predicting the risk of high-risk projects. Therefore, the FIS-RPN method has been used to improve the traditional environmental risk assessment-RPN in the construction and operation stages of the dam. A comparison of FIS-RPN and traditional-RPN methods in the dam construction phase shows that the soil erosion environment has the highest RPN compared to other risk environments, with the difference that traditional-RPN is 189 and FIS-RPN is 417. Likewise, in the operation phase, the Aquatic environment has the highest RPN, which is 133 in traditional RPN and 342 in FIS-RPN. These results indicate that the urgency of action evaluation criteria in FIS-RPN is much more serious than in traditional-RPN and it is necessary to specifically identify and evaluate risk environments. Therefore, the FIS-RPN method is proposed to improve the traditional environmental risk assessment-RPN in the construction and operation stages of Eyvashan dam. The result of FIS-FMEA model shows that the proposed framework can be useful in evaluating the environmental effects of dams with critical risk values compared to traditional-FMEA.

Conflicts of interest/Competing interests

The authors declare they have no competing interests

Funding

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Ethics Declaration statement

The research was in accordance with a declaration of Helsinki standards.

Consent to Participate

The manuscript is eligible for consent to participate.

Consent for publication

The manuscript is eligible for consent to publication.

Availability of data and material/ Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

BB, TR: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Writing – review & editing.BB: Resources; Software; Roles/Writing – original draft; TR: Supervision.

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