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Fuzzy and Classical MCDM Techniques to Rank the Slope Stabilization Methods in a Rock-Fill Reservoir Dam

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Abstract

Slope stabilization is one of the most crucial tasks in rock-fill reservoir dam projects to prevention of erosion and destruction of upstream and downstream slopes. Inappropriate choice and design of the protection can cause irreparable damages imposing additional costs and time to the project. In this paper, the body slope ranking is conducted by using the classical and fuzzy multi-criteria decision making approaches specifically VIKOR and Fuzzy-TOPSIS methods. To this aim, eight important and effective criteria were considered to select the most appropriate cover among five most common ones for protecting and conserving body slope of the rock-fill dams. The study was conducted on a dam in Bijar city located in the province of Guilan, the north of Iran. According to results of a comparative analysis using fuzzy and classical MCDM techniques, the concrete facing cover and the soil-cement cover have placed at the highest and lowest ranks to protect the body of the dam, respectively, suggested by both employed methods.

Keywords: Slope Stabilization; Rock-Fill Reservoir Dam; Multi-Criteria Decision Making; Fuzzy-TOPSIS; VIKOR.

1. Introduction

The global water crisis and management of water resources have accelerated the requirement for the construction of dams; hence, in recent decades, the constructions of dams in the world and especially in Iran are in a special position. Dam design and stability are the most important issues that engineers are encountered. The earth dam is designed for different parts including slope upstream and downstream of the dam. Additionally, slope protecting cover of dam is important for the protection and stability. The importance is that an incorrect design and an unsuitable protection cover of earth dams can lead to slope instability and irreparable social, financial, and environmental damages [1-2]. Therefore, choosing an appropriate cover for slope stability of dams is a very important part of the design. There are several approaches for selection and evaluation of the body slope protection such as numerical methods [3-4]. As an instance, Zartaj et al. (2012) utilized finite element method (FEM) for evaluating the stability of earth dam with geotextile using PLAXIS 3D [5]. However, most of the times there is probability of failures and defects because of uncertainty in implementation and collection of data and also lack of consideration in many other parameters. These issues can lead to failure in the phase of selecting the type of cover for the stability and design; hence, one of the designers' activities is

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preparing and gathering all data related to economic issues and performance optimization according to time condition and project necessity. These conditions depend on the variable selection and they are not the same in all cases. So, in slope stabilization and optimization, there is not a specific method as a solution because there are differences between criteria and selections. In fact, selection of the suitable method of dam slope stabilization is considered as a multi-criteria decision making problem. A research was conducted by Ahangari et al. (2010) in order to identify effective and impressive criteria. They considered several criteria in order to analyze stabilization methods in the phase of decision making including technical, managerial, financial, environmental, and socio-cultural considerations [6]. Lim et al. (2015) evaluated slope stability analysis. They used the three-dimensional analysis. Based on their results obtained, they made some recommendations for the evaluation of slope stability [7]. Qi et al. (2015) investigated slope stability using three methods. The results demonstrated that the numerical modeling can be applied as a powerful tool for modeling slope stability [8]. Fattahi (2016) carried out investigations for prediction of slope stability using the soft computing methods including the adaptive neuro-fuzzy inference system (ANFIS) based on clustering methods. The results obtained showed the ANFIS-SCM model is a reliable system modeling technique for prediction of slope stability [9].

In this research, the multi-criteria decision making (MCDM) methods enhanced by fuzzy logic are utilized to rank the possible slope stabilization methods for a rock-fill reservoir dam in Bijar, northern Iran. The Bijar dam is designed with the aim of providing urban and industrial water supply and public consumption in Guilan province, Iran which was constructed on a branch of Sefidrud River. It is located 8 kilometers far from Shahr-e-Bijar village and 35 km from Rasht City, on Zilky River in Guilan province. Technical specifications of the dam include dam crest elevation: 219.5 m (from sea level), dam height: 94.5 m (from basement), crest height: 430 m, spillway: free spillway in the right bank end in to cascading shoot, excavation volume: 2.7 million cubic meters, embankment volume: 4.6 million cubic meters, concrete volume: 272,000 cubic meters, total length of tunnel & galleries: 1,125 m, diameter of tunnel & galleries: 4.7 to 2.5 m, and total length of grouting curtain: 712 m.

For this aim, the Fuzzy-TOPSIS and VIKOR techniques are employed considering various criteria and alternatives under uncertain conditions. A number of experts are asked to score the related questionnaires of both decision making methods and the information is utilized in the framework of the fuzzy and classical analyses. The results of two methods are finally compared and evaluated.

2. Fuzzy-TOPSIS

The "Technique for Order Performance by Similarity to Ideal Solution (TOPSIS)" was introduced by Hwang and Yoon (1981) for ranking of alternatives through a very reasonable mathematical approach which is a powerful tool according to its ideal similarity [10]. This method was founded based on the two principles of positive and negative ideal solutions. In recent years, this method has been widely used for solving multi-criteria decision making and ranking problems. There are several applications of this methodology in the fields of earth sciences and geographic information system as well as mining operation issues [11-14].

In many engineering problems, we may face unpredicted and uncertain criteria and alternatives. The fuzzy logic is a suitable and impressive approach for dealing with complex issues related to making a choice from among some options which provide a comparison of the considered alternatives. Fuzzy logic is in fact the opposite of classical logic. The boundary of Fuzzy sets unlike that of classic sets is implicit and uncertain, namely, it is bound. All information related to a fuzzy set is described by its membership function and used in all applications of fuzzy set theory [15-16]. Hence, the concept of membership function has a special place in the fuzzy sets theory. In fact, by corresponding any value in the interval (0~1) to any membership degree of members in a fuzzy set, we can extend a classic set to fuzzy set. In general, in complex problems that classical mathematics' analysis is difficult, the theory of fuzzy logic is an appropriate solution to resolve these limitations [17].

The introduction of fuzzy logic by Professor Lotfi Askar Zadeh in 1965 and his article on information and control periodical under the title "Fuzzy Sets" and then the works of other researchers such as Kaufmann & Gupta (1988) and Zimmermann (1992) had an important role in developing of this theory [18-19]. This logic has led to many advances in numerous sciences, especially engineering science. The fuzzy sets theory has a wide variety of applications. Fuzzy decision making problems are one of the most efficient applications of fuzzy sets theory in the fuzzy logic. The Fuzzy multi-criteria decision-making is frequently employed by researchers in other sciences, including geotechnical engineering, rock mechanics, mining engineering, operations research [20-24].

Chen and Hwang (1992) presented the fuzzy-TOPSIS method. In this context, there are eight defined steps for this technique by multiple options and criteria, which are described as follows [23-24].

2.1. Formation of Decision-making Matrix

Decision- making matrix is formed based on the current available alternatives and required criteria for evaluating the alternatives. Also, the value $\tilde{x}_{ij}$ for fuzzy triangular numbers is equal to $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$ where $\tilde{x}_{ij}$ is the function of alternative i (i= 1, 2, 3,..., m) in relation to criterion j (j= 1, 2,3,..., n) [25].

$$\tilde{A} = \begin{pmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mm} \end{pmatrix}$$

Tables 1. and 2. are used to constitute fuzzy decision matrix and weight vector of the criteria, respectively. Figures 1. and 2. show them.

Table 1. Linguistic Variables to Assess the Criteria Significance

Corresponding Fuzzy Number	Linguistic Variable
(0,0,0.1)	Very Low Preferred(VLP)
(0,0.1,0.3)	Low Preferred (LP)
(0.1,0.3,0.5)	Medium-Low Preferred (MLP)
(0.3,0.5,0.7)	Indifferent (IND)
(0.5,0.7,0.9)	Medium-High Preferred (MVP)
(0.7,0.9,1)	High Preferred (HP)
(0.9,1,1)	Very High Preferred (VHP)

Table 2. Linguistic Variables to Rank Options

Corresponding Fuzzy Number	Linguistic Variable
(0,0,1)	Very Low (VL)
(0,1,3)	Low (L)
(1,3,5)	Medium-Low (ML)
(3,5,7)	Medium (M)
(5,7,9)	Medium-High (MH)
(7,9,10)	High (H)
(9,10,10)	Very High (VH)

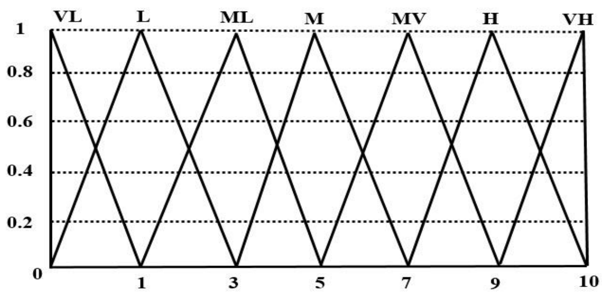

Figure 1. Linguistic variables to rank option

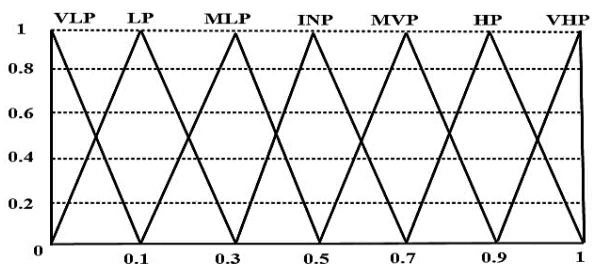

Figure 2. Linguistic variables to assess the criteria significance

2.2. Determination of the Matrix of Criteria Weight

After the formation of decision matrix based on the Equation 1, the importance of different criteria is determined as following:

$$\tilde{W} = [\tilde{w}_1, \tilde{w}_2, \ldots\ldots, \tilde{w}_n] \quad (1)$$

2.3. Normalization of the Matrix of Fuzzy Decision

In the fuzzy technique for order performance by similarity to ideal method unlike the classical technique, changing linear scale instead of complicated methods is used for normalization. In addition, while x_{ij} 's and r_{ij} 's are fuzzy, Equations 2. and 3. are used in normalization matrix for positive and negative criteria, respectively [25].

$$\tilde{r} = [\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}] \quad (2)$$

$$\tilde{r} = [\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}] \quad (3)$$

The values c_j^* and a_j^- in above equations are gained from Equations 4. and 5, respectively.

$$c_j^* = \max_i c_{ij} \quad (4)$$

$$a_j^- = \min_i a_{ij} \quad (5)$$

Therefore, the fuzzy decision matrix is normalized based on Equation 6, where M and N values indicate the number of alternatives and criteria, respectively.

$$\tilde{R} = [\tilde{r}_{ij}]_{m \times n} \qquad i=1,2,3,\ldots,m \quad , \quad j=1,2,3,\ldots,n \quad (6)$$

2.4. Determination of the Weighing Fuzzy Decision Matrix

In order to determine the weighing fuzzy decision matrix in terms of the weight of different criteria, the importance coefficient related to each scale is multiplied by normalization matrix according to Equation 7.

$$\tilde{V} = [\tilde{v}_{ij}]_{m \times n} \quad i=1,2,3,\ldots,m \quad j=1,2,3,\ldots,n \quad (7)$$

This matrix of triangular fuzzy numbers for criteria with positive and negative aspects is based on Equations 8. and 9.

$$\tilde{v} = \tilde{r}_{ij}.\tilde{w}_j = [\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}].(w_{j1}, w_{j2}, w_{j3}) \quad (8)$$

$$\tilde{v} = \tilde{r}_{ij}.\tilde{w}_j = [\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}].(w_{j1}, w_{j2}, w_{j3}) \quad (9)$$

2.5. Fuzzy Positive Ideal Solution (FPIS, A*) and Fuzzy Negative Ideal Solution (FPIS, A⁻)

Based on Equations 10. and 11, Positive and Negative Ideal Solution are achieved as follows:

$$A^* = \{\tilde{v}_1^*, \tilde{v}_2^*, \tilde{v}_3^*, \ldots\ldots, \tilde{v}_n^*\} \quad (10)$$

$$A^- = \{\tilde{v}_1^-, \tilde{v}_2^-, \tilde{v}_3^-, \ldots\ldots, \tilde{v}_n^-\} \quad (11)$$

2.6. Calculation of Distance from Fuzzy Positive Ideal Solution and Fuzzy Negative Ideal Solution

For determination of the distance from fuzzy positive ideal and negative ideal for every alternative, Equations 12. and 13. are used.

$$S_i^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^*) \quad (12)$$

$$S_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-) \quad (13)$$

Where (d) is distance between two fuzzy numbers in the Equations 12 and 13.

2.7. Ranking Based on the Closeness Coefficient (CC)

At this stage, the Closeness Coefficient is obtained from Equation 14.

$$CC_i = \frac{S_i^-}{S_i^* + S_i^-} \qquad i=1,2,3,.....,m \tag{14}$$

At the final stage based on similarity index, alternatives are classified and those with more similarity index are of the first priority.

3. VIKOR Method

The VIKOR algorithm is based on a compromise programming method of multi-criteria decision-making and one of the most effective and useful methods in this field with non-commensurable and conflicting criteria, firstly proposed by Opricovic (1998) [26]. In later years, this method has been developed and used in other scientific and technical disciplines such as ranking of risks, civil engineering, economics, operations research, geotechnical and mining engineering [27-29].

An analytical model with VIKOR approach was proposed by Chang & Hsu (2009) for prioritizing land-use restraint strategies in the Tseng-Wen reservoir watershed [30]. A compromise solution in water resources planning has been carried out by Opricovic (2009) [31]. A research on evaluating the credit-risk in power enterprise was investigated by Huang & Yan (2008) using VIKOR and SVM methods. In VIKOR algorithm with (m) options and (n) criteria, seven steps have been defined [32].

3.1. Formation of Decision Matrix

Decision matrix (K) according to the number of criteria and options will be formed to evaluate alternatives based on criteria as follows:

$$K = \begin{pmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mm} \end{pmatrix}$$

Where x_{ij} is function of i^{th} option (i=1,2,3,….,m) in relation to j^{th} criterion.

3.2. Formation of Decision Matrix

At this step, the decision matrix will be normalized and matrix (F) will be as follows:

$$F = \begin{pmatrix} f_{11} & f_{12} & \cdots & f_{1n} \\ f_{21} & f_{22} & \cdots & f_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ f_{m1} & f_{m2} & \cdots & f_{mn} \end{pmatrix}$$

In this matrix, fij is obtained from Equation 15.

$$f_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{15}$$

3.3. Determination of the Weight Vector of Criteria

The weight vector of criteria is obtained based on its relative importance as Equation 16, where w_i is the relative importance of criteria (i= 1,2,3,…..,n).

$$W = [w_1, w_2, w_3, ..., w_n] \tag{16}$$

3.4. Determination of the Best f_j^* and the Worst f_j^- Values of all Criterion Functions

f_j^* and f_j^- are the best and the worst values of (j) criterion among all criteria functions. The best f_j^* and the worst f_j^- values of positive and negative criterion are obtained from Equations 17. to 20.

$$f^*_j = \underset{i}{\mathrm{Max}}\, f_{ij} \quad (17)$$

$$f^*_j = \underset{i}{\mathrm{Min}}\, f_{ij} \quad (18)$$

$$f^-_j = \underset{i}{\mathrm{Min}}\, f_{ij} \quad (19)$$

$$f^-_j = \underset{i}{\mathrm{Max}}\, f_{ij} \quad (20)$$

3.5. Calculation of the Utility Measure (S) and Regret Measure (R)

S and R are defined by Equations 21 and 22.

$$S_i = \sum_{j=1}^{n} w_j \frac{f^*_j - f_{ij}}{f^*_j - f^-_j} \quad (21)$$

$$R_i = \mathrm{Max}\left\{ w_j \frac{f^*_j - f_{ij}}{f^*_j - f^-_j} \right\} \quad (22)$$

3.6. Ranking of the Order of Preference Based on Values R, S and Q

The amount of Vikor Index (Q) is calculated as follows:

$$Q_i = \upsilon \left[\frac{S_i - S^-}{S^* - S^-} \right] + (1-\upsilon) \left[\frac{R_i - R^-}{R^* - R^-} \right] \quad (23)$$

$$S^* = \mathrm{Max}\, S_i \quad , \quad S^- = \mathrm{Min}\, S_i \quad , \quad R^* = \mathrm{Max}\, R_i \quad , \quad R^- = \mathrm{Min}\, R_i$$

In fact, $\left[\frac{S_i - S^-}{S^* - S^-} \right]$ and $\left[\frac{R_i - R^-}{R^* - R^-} \right]$ are rates of distance from the positive and negative ideal solution, respectively. v is the weight of the maximum group utility and it is usually supposed 0.5 [33-34].

3.7. Ranking of the Order of Preference Based on Values R, S and Q

The preferred option is the one with the lowest value of Q index which satisfies the following two conditions:

1) If A1 and A2 options have the first and second ranks of Q index and n is the number of alternatives, Equation 24. will be established.

$$Q(A_2) - Q(A_1) \geq \frac{1}{n-1} \quad (24)$$

2) A1 option should be the preferred option in at least one of the groups R and S.

4. Application

4.1. Evaluation Alternatives and Criteria

The present study is conducted on Bijar dam in northern Iran (Figure 3). That is one of the most important earth dams in Iran located on an important river in the area to supply public, agricultural and industrial water consumption.

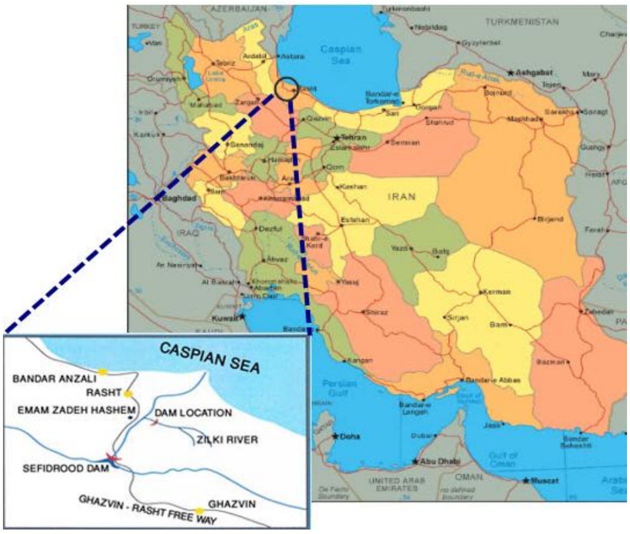

Figure 3. Location of the Dam [35]

Based on the resources, publications and experts' comments, five major common methods were considered as alternatives to protect body covers of upstream slopes including "Concrete facing cover" (A1), "Rip rap" (A2), "Asphalt concrete cover" (A3), "Soil-cement cover" (A4), and "Geo-synthetic materials" (A5). In addition, 17 criteria were taken into consideration based on the initial data through experience after several meetings, consultations and brain storming with the experts. Eight most effective criteria were finally selected including the "Economical capability" (C1), "Cut-off" (C2), "Resistance against the environment factors" (C3), "Ductility" (C4), "Access to materials" (C5), "Hardship of doing the job" (C6), "Environmental effects" (C7), and "Long time taking of the project" (C8). Among them, the first five criteria have positive aspects and the next three are negative. These problem criteria and decision alternatives can be shown in hierarchical structure like what is seen in Fig. 4.

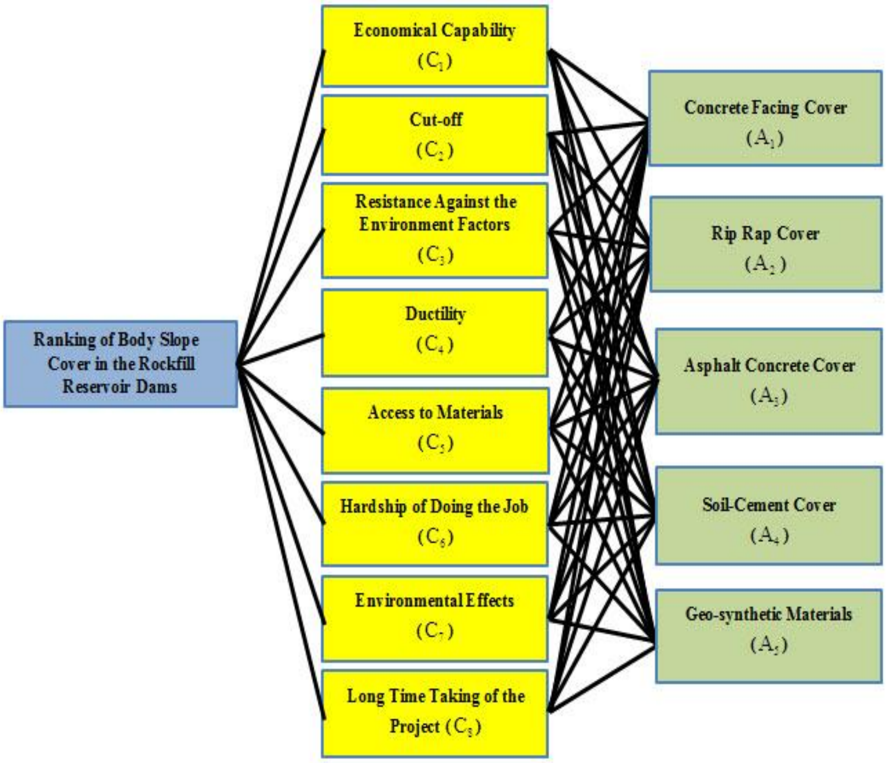

Figure 4. Hierarchical design of the problem

4.2. Decision Making by FTOPSIS

Tables 3 and 4. show the fuzzy decision matrix and fuzzy weight vector of criteria based on experts' opinions, respectively. Triangular fuzzy numbers are hence used to define the parameters in this research according to Tables 1 and 2.

Table 3. Matrix of fuzzy decision of FTOPSIS

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
A_1	(5.13,7.05,8.57)	(6.8,8.57,9.65)	(7.61,9.32,10)	(3.98,6.46,7.94)	(6.8,8.57,9.65)	(1.44,3.57,5.59)	(6.08,7.88,9.65)	(1.71,3.98,6.08)
A_2	(3.56,5.59,7.61)	(4.72,6.8,8.57)	(6.8,8.57,9.65)	(0,3.27,5.74)	(0,2.47,4.72)	(3.98,6.46,7.94)	(4.72,6.8,8.57)	(5.13,7.05,8.57)
A_3	(6.08,7.88,9.32)	(7.39,8.88,9.65)	(8.28,9.65,10)	(0,1.44,3.57)	(6.24,7.94,8.88)	(2.08,4.22,6.26)	(2.47,4.72,6.8)	(3.56,5.59,7.61)
A_4	(2.47,4.72,6.8)	(2.08,4.22,6.26)	(2.76,5.13,7.05)	(0,1.71,3.98)	(5.59,7.61,9.32)	(4.72,6.8,8.57)	(6.8,8.57,9.65)	(4.32,6.3,7.88)
A_5	(2.92,5.28,7.4)	(0,1.71,3.98)	(5.28,7.4,8.88)	(0,2.08,4.22)	(3.56,5.59,7.61)	(1,3,5)	(1.44,3.56,5.59)	(2.08,4.22,6.26)

Table 4. Weight vector of criteria of FTOPSIS

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
Criterion Weight	(0.63,0.83,0.97)	(0.68,0.86,0.97)	(0.83,0.97,1)	(0.47,0.68,0.86)	(0.29,0.47,0.68)	(0.14,0.36,0.56)	(0.56,0.76,0.93)	(0,0.17,0.39)

Table 5. shows the normalized weighting decision matrix determined based on the pseudo-codes of FTOPSIS and Equation 1. to 9.

Table 5. Normalized matrix of fuzzy decision of FTOPSIS

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
A_1	(0.35,0.63,0.89)	(0.48,0.77,0.97)	(0.64,0.9,1)	(0.24,0.55,0.86)	(0.2,0.42,0.68)	(0.03,0.1,0.39)	(0.08,0.14,0.22)	(0,0.07,0.39)
A_2	(0.24,0.49,0.79)	(0.33,0.6,0.86)	(0.56,0.83,0.97)	(0,0.28,0.62)	(0,0.12,0.33)	(0.02,0.05,0.14)	(0.1,0.16,0.29)	(0,0.04,0.13)
A_3	(0.41,0.71,0.97)	(0.52,0.79,0.97)	(0.69,0.94,1)	(0,0.12,0.39)	(0.19,0.39,0.63)	(0.02,0.09,0.27)	(0.12,0.24,0.54)	(0,0.05,0.18)
A_4	(0.17,0.42,0.71)	(0.15,0.38,0.63)	(0.23,0.49,0.71)	(0,0.15,0.43)	(0.17,0.37,0.66)	(0.02,0.05,0.12)	(0.08,0.13,0.2)	(0,0.06,0.16)
A_5	(0.19,0.47,0.76)	(0,0.15,0.39)	(0.43,0.72,0.89)	(0,0.18,0.45)	(0.12,0.27,0.54)	(0.3,0.12,0.56)	(0.15,0.3,0.93)	(0,0.07,0.32)

Therefore, the fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS) are determined according to Table 5. and Equations 10. and 11, as follows:

$$A^* = \left\{ \begin{array}{l} (0.97, 0.97, 0.97), (0.97, 0.97, 0.97), (1,1,1), (0.86, 0.86, 0.86), \\ (0.68, 0.68, 0.68), (0.56, 0.56, 0.56), (0.93, 0.93, 0.93), (0.39, 0.39, 0.39) \end{array} \right\}$$

$$A^- = \{(0.17, 0.17, 0.17), (0,0,0), (0.23, 0.23, 0.23), (0,0,0), (0,0,0), (0.02, 0.02, 0.02), (0.08, 0.08, 0.08), (0,0,0)\}$$

For each alternative, distance of FPIS, distance of FNIS and closeness coefficient (CCi) are calculated based on Equations 12 to 14. The results are shown in Table 6.

$$S_i^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^*)$$

$$S_{11}^* = \sqrt{\frac{1}{3}\left[(0.35-0.97)^2 + (0.63-0.97)^2 + (0.89-0.97)^2\right]} = 0.41$$

$$S_{15}^* = \sqrt{\frac{1}{3}\left[(0.2-0.68)^2 + (0.42-0.68)^2 + (0.68-0.68)^2\right]} = 0.32$$

$$S_{12}^* = \sqrt{\frac{1}{3}\left[(0.48-0.97)^2 + (0.77-0.97)^2 + (0.97-0.97)^2\right]} = 0.31$$

$$S_{16}^* = \sqrt{\frac{1}{3}\left[(0.03-0.56)^2 + (0.1-0.56)^2 + (0.39-0.56)^2\right]} = 0.42$$

$$S_{13}^* = \sqrt{\frac{1}{3}\left[(0.64-1)^2 + (0.9-1)^2 + (1-1)^2\right]} = 0.22$$

$$S_{17}^* = \sqrt{\frac{1}{3}\left[(0.08-0.93)^2 + (0.14-0.93)^2 + (0.22-0.93)^2\right]} = 0.78$$

$$S_{14}^* = \sqrt{\frac{1}{3}\left[(24-0.86)^2 + (0.55-0.86)^2 + (0.86-0.86)^2\right]} = 0.4$$

$$S_{18}^* = \sqrt{\frac{1}{3}\left[(0-0.39)^2 + (0.07-0.39)^2 + (0.39-0.39)^2\right]} = 0.29$$

$$S_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-)$$

$$S_{11}^- = \sqrt{\frac{1}{3}\left[(0.35-0.17)^2 + (0.63-0.17)^2 + (0.89-0.17)^2\right]} = 0.5$$

$$S_{15}^- = \sqrt{\frac{1}{3}\left[(0.2-0)^2 + (0.42-0)^2 + (0.68-0)^2\right]} = 0.48$$

$$S_{12}^- = \sqrt{\frac{1}{3}\left[(0.48-0)^2 + (0.77-0)^2 + (0.97-0)^2\right]} = 0.77$$

$$S_{16}^- = \sqrt{\frac{1}{3}\left[(0.03-0.02)^2 + (0.1-0.02)^2 + (0.39-0.02)^2\right]} = 0.22$$

$$S_{13}^- = \sqrt{\frac{1}{3}\left[(0.64-0.23)^2 + (0.9-0.23)^2 + (1-0.23)^2\right]} = 0.64$$

$$S_{17}^- = \sqrt{\frac{1}{3}\left[(0.08-0.08)^2 + (0.14-0.08)^2 + (0.22-0.08)^2\right]} = 0.09$$

$$S_{14}^- = \sqrt{\frac{1}{3}\left[(24-0)^2 + (0.55-0)^2 + (0.86-0)^2\right]} = 0.61$$

$$S_{18}^- = \sqrt{\frac{1}{3}\left[(0-0)^2 + (0.07-0)^2 + (0.39-0)^2\right]} = 0.23$$

$$S_1^* = 0.41 + 0.31 + 0.22 + 0.4 + 0.32 + 0.42 + 0.78 + 0.29 = 3.15$$

$$S_1^- = 0.5 + 0.77 + 0.64 + 0.61 + 0.48 + 0.22 + 0.09 + 0.23 = 3.54$$

$$CC_1 = \frac{3.54}{3.15 + 3.54} = 0.529$$

Table 6. Distance between each alternative's (s_i^*, s_i^-) and closeness coefficient

	A_1	A_2	A_3	A_4	A_5
Distance of Fuzzy Positive Ideal Solution	3.15	3.96	3.27	4.4	3.96
Distance of Fuzzy Negative Ideal Solution	3.54	2.48	3.23	2.04	2.81
Closeness Coefficient	0.529	0.385	0.497	0.317	0.415

Figure 5. shows the ranking of body slope cover using FTOPSIS for the considered case study. As seen, concrete facing cover (A1) option has the highest ranking among other alternatives. The next ranks are assigned to asphalt concrete cover (A3), geo-synthetic materials (A5), and rip rap (A2), respectively, and lastly to soil-cement cover (A4).

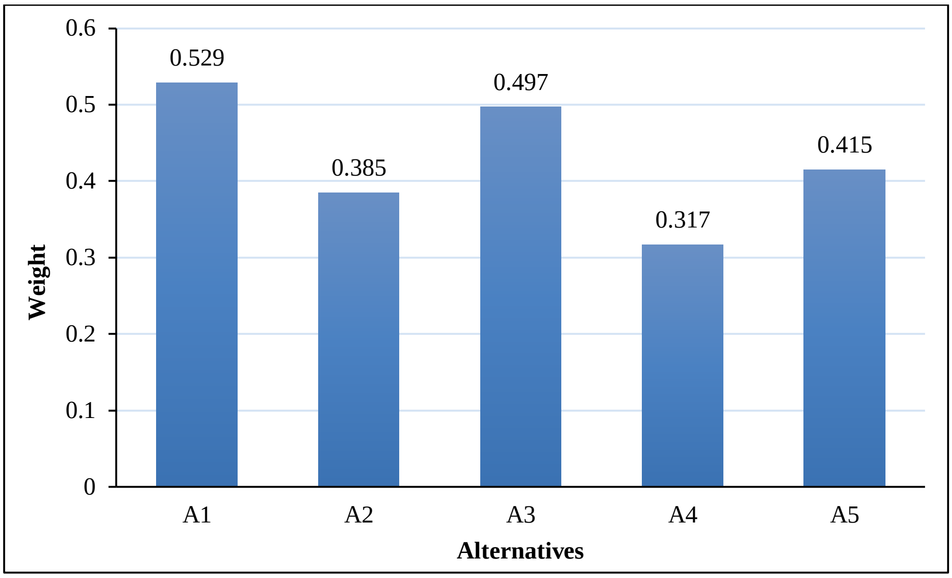

Figure 5. Ranking of Body Slope Cover in the Bijar reservoir dam by FTOPSIS

4.3. Decision Making by VIKOR

The importance coefficients of criteria and normalized decision matrix are shown in Tables 7. and 8. based on investigations and evaluations. Based on Equations 17. to 20. and Table 8, the best and worst values of criteria are calculated and the results are shown in Table 9.

Table 7. Importance coefficients of criteria of VIKOR

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
Weight Vector	0.194	0.238	0.321	0.054	0.069	0.022	0.085	0.017

Table 8. Normalized decision matrix of VIKOR

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
A_1	0.605	0.636	0.619	0.319	0.502	0.424	0.431	0.368
A_2	0.318	0.212	0.4	0.446	0.443	0.326	0.388	0.295
A_3	0.465	0.495	0.51	0.382	0.473	0.448	0.459	0.405
A_4	0.375	0.354	0.255	0.51	0.425	0.473	0.529	0.516
A_5	0.42	0.424	0.364	0.542	0.384	0.538	0.416	0.589

Table 9. The best and worst values of criteria of VIKOR

Criteria Alternatives	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
f^*_j	0.605	0.636	0.619	0.542	0.502	0.538	0.529	0.589
f^-_j	0.318	0.212	0.255	0.319	0.384	0.326	0.388	0.295

The utility measure (S), regard measure (R) and Q index of VIKOR are determined according to Equation 21. to 23. and assuming $\upsilon = 0.5$. The final ranking based on values of (S), (R) and Q index are shown from smaller to larger ratings in Table 10.

Table 10. Ranking matrix of VIKOR

Ranking based on values of (Q)		Ranking based on values of (S)		Ranking based on values of (R)	
0	A_1	0.094	A_1	0.054	A_1
0.286	A_3	0.387	A_3	0.096	A_3
0.674	A_5	0.593	A_5	0.225	A_5
0.761	A_2	0.683	A_2	0.238	A_2
1	A_4	0.801	A_4	0.321	A_4

$$Q_{A2}(0.286)-Q_{A1}(0)\geq\frac{1}{5-1}$$

$$=\ 0.286\geq 0.2$$

In addition, necessary and sufficient conditions are established according to Equation 24. Based on the results, the ranking of body slope cover in the Bijar dam by VIKOR method will be: $A_1>A_3>A_5>A_2>A_4$.

The resulted ranking by the VIKOR method is the same as what FTOPSIS suggests and hence two employed classical and fuzzy methods in this paper recommend the use of soil-cement cover as the best stabilization method and oppose the use of soil-cement cover for this purpose.

In comparison between the Fuzzy-TOPSIS and VIKOR methods, the obtained results show that the concrete facing cover and soil-cement cover have the highest and lowest rates for both methods, respectively. The advantage of these approaches to rank the slope stabilization methods in a rock-fill reservoir dam is combination of experienced technicians and use of geotechnical studies. Consequently, it can be concluded that these methods are the reliable system modelling techniques for evaluation and ranking the slope stabilization with highly acceptable degrees of accuracy. In fact, the Fuzzy-TOPSIS and VIKOR methods contribute greatly to the evaluation of uncertain issues without extra assumptions.

5. Conclusion

The main purpose of this paper was to rank the slope stabilization methods for body slope cover in a rock-fill reservoir dam using the classical and fuzzy multi-criteria decision making methods. To this aim, Fuzzy-TOPSIS and VIKOR methods were employed and several experts from different related fields were chosen and asked to share their viewpoints on the problem. The most strong point of our study is the ability to deal with model uncertainty and multiple criteria decision making in ranking options using linguistic variables and fuzzy logic. Accordingly, eight most related criteria were selected along with five most common stabilizing/protecting techniques to be applied in the case study of this research located in northern Iran. The present study in Shahr-e-Bijar reservoir dam in the north of Iran showed that the concrete facing cover and soil-cement cover have the highest and lowest rates, respectively, among all the considered methods concluded by both FTOPSIS and VIKOR methods. The results of this research can be used in design and management phase of project management in similar dam construction projects.

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