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RESEARCH ARTICLE

Using the AHP and Fuzzy-AHP Decision Making Methods to Optimize the Dam Site Selection in illustrative basin in the center of Iran

Hamed Koohpayehzadeh Esfahani[1] and Mohsen Sadegh Amal Nik [2,3]

1. Department of Environment, University of Tehran, Tehran, Iran

2. Faculty of Indastrial Engineeing, University of Tehran, Tehran, Iran

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Corresponding Author

Hamed Koohpayehzadeh Esfahani

Abstract

Security and reduction of vulnerability of the infrastructures, as a target of conflict, disorder and terrorism have been considered by various countries since the past up to now. In this regard, the militarization of important infrastructures such as dams is not always an effective option in establishing security firstly because of high costs of security establishment and then revelation of the strategic spaces. Nowadays, planners have started to think more creatively about how they can hide security behind site selecting, planning and design features. With emphasis on passive defense concept all around the world, defining new spatial logics and including related policies in site selection incorporating the environmental issues. The importance of selected basin, as a close site to Tehran (capital of Iran) that can provide water demands for agriculture and potable usage, has made application of passive defense policies necessary. So the goal of this research is to assess the environmental impact of dam site selection with AHP and Fuzzy-AHP methods resulting from principles and policies of passive defense and to formulate appropriate framework of spatial development policy making for vulnerability reduction.

In order to storage and use of water resources and reduce the environmental impacts, optimization of choosing the dam place is very important in water usage strategies and water resource management. Analytical Hierarchy Process (AHP) have possible in using the linguistic variables along quantitative variables and essentially is based on expert opinions. In recent years in order to increase the capability of AHP, this method combined with fuzzy method and in the Fuzzy-AHP algorithm is presented. In this paper, analytic hierarchy process (AHP), one of multi-criteria decision making (MCDM) techniques in fuzzy environment is applied to select the optimal alternative for construction of a dam in a case study. Results show that using AHP in the fuzzy environment improves decision making through considering more important factors in decision making.

INTRODUCTION

Water shortage in arid and semi-arid regions is one of the problems of policy makers. Various solutions have been used to overcome this problem around the world. One of such solutions is construction and use of dams. In recent years, efforts have been made at national level to use dams more because of increase in severity, extent, and frequency of droughts. Thus, steps were taken quickly so as to facilitate construction of more such dams in the country. Since construction and operations of these dams is a new technique in water resource management in Iran, the present paper attempts to compare application of two methods of fuzzy analytic hierarchy process and analytic hierarchy process. The aim of this comparison is to familiarize experts with these methods and to specify the strengths and weaknesses of these two methods.

Underground dams are built for different purposes such as prevention of saltwater and freshwater interference (Garagunis, 1981), avoidance of underground water penetration in the mines (Gupta et al., 1987), prevention of seawater into freshwater aquifers (Onder and yilmaz, 2000), and holding water for operation (Nilsson, 1988). Basically, several factors influence on selection of an alternative for construction of underground dams. Taking into account all of these factors makes the decision making problem so complex. Thus, multi-criteria decision making (MCDM) methods are applied to tackle this problem. One widely used MCDM method is the analytic hierarchy process (AHP) which has been used in various managerial areas from hydrogen production methods (Pilavachi et al., 2009). In addition, AHP has been applied for water resource management in many studies such as Anagnostopoulos et al. (2005, 2007), Srdjevic (2007), Mei et al. (1989), Akpinar et al. (2005), Okada et al. (2008), and Montazar and Zadbagher (2010). Montazar and Behbahani (2007) developed an optimized irrigation system selection model using analytic hierarchy process.

As standard hierarchical analysis process is not effective to solve more complicated problems, therefore, some modifications are necessary for this method. Combining fuzzy methods with analytic hierarchy process is one approach for solving the complicated problems. Fuzzy analytic hierarchy process (fuzzy AHP) has been applied in different problems as follows: in geographical information system (GIS) application (Vahidnia et al., 2008), risk evaluation of information technology projects (Iranmanesh et al., 2008), water management plans assessment (Srdjevic and Medeiros, 2008), and eco-environmental vulnerability assessment (Li et al., 2009). Stirn (2006) andKong and Liu (2005) applied fuzzy analytic hierarchical process to evaluate success factors of e-commerce. They stressed that fuzzy AHP has qualifications of both subjective and thematic factors in the decision making process. Ascough et al. (2008), Alias et al. (2009), Opricovic (2011) and Tsiko and Haile (2011) developed this methodology for other environmental issues.

Locating underground dam construction projects is a high complex and non-linear problem due to existence of uncertainty in factors influencing on it. Since the real world is full of ambiguities and imprecise and vague terms, most decision makers in field of underground dam construction know using linguistic terms more practical and feasible (Zadeh, 1965). In the current study, a useful and practical methodology is presented for group decision making on the location of underground dams construction based on the AHP and fuzzy theory. The rest of the paper, describes the proposed methodology; the proposed methodology is applied to locate the underground dam construction as an experiment and results are provided; the proposed methodology is tested for the verification and validation purposes; finally conclusions of the present work.

1. Proposed Methodology

In this section, the proposed fuzzy AHP based methodology is presented for evaluating and selecting the best location for underground dam construction location. The steps of the proposed methodology are illustrated in Figure 1. The steps will be implemented in a case study and described in great details.

2.1 Fuzzy Analytic Hierarchy Process

AHP is a decision making method for decomposing the hierarchical problem and can apply to solve a complex multi-criteria decision problem (Saaty, 1980). In the literature, AHP has widely been applied to solve the different MCDM problems. Many times decision makers are only able to provide a subjective and uncertain answer rather than an exact value (Shaw et al., 2012). Hence, such answers need to be quantified. Conventional methods of AHP cannot be used for decision making problem in the real world when fuzziness and vagueness is observed in data of problems. To handle such uncertainties and vagueness, fuzzy sets theory, initially introduced by Zadeh (1965), can be applied. Therefore, incorporation of the fuzzy concept with AHP can be more applicable and more effective than the conventional AHP in the real world problems. This issue has attracted many researchers to apply fuzzy AHP in different fields such as risk and disaster management (Takács, 2010), work safety evaluation (Zheng et al., 2012), green initiatives in the fashion supply chain (Wang et al., 2012).

Figure 1 shows the proposed fuzzy AHP based methodology for decision making on selection of the best location form underground dam construction. The steps of the proposed methodology are as follows:

Step1: ***Determining Criteria and Alternatives and Establish hierarchal structure***

The first step of our methodology is to determine the criteria which are going to be affected for making a decision about underground dam construction location.

Step 2: ***Collecting experts' judgments based on fuzzy scale and establish fuzzy pair-wise comparison matrices***

The sample questionnaire by Azadeh et al. (2010, 2011) and Nazari-Shirkouhi et al. (2011) can be applied to collect the experts' judgments based on fuzzy scales. In the present paper, the triangular fuzzy numbers (TFNs) for fuzzy membership function applied to enable the decision maker to make easier decisions (Kaufmann and Gupta, 1988). The membership function of a TFN is shown in Equation (1). The TFN is usually shown with A= (l, m, u), where $l \leq m \leq n$

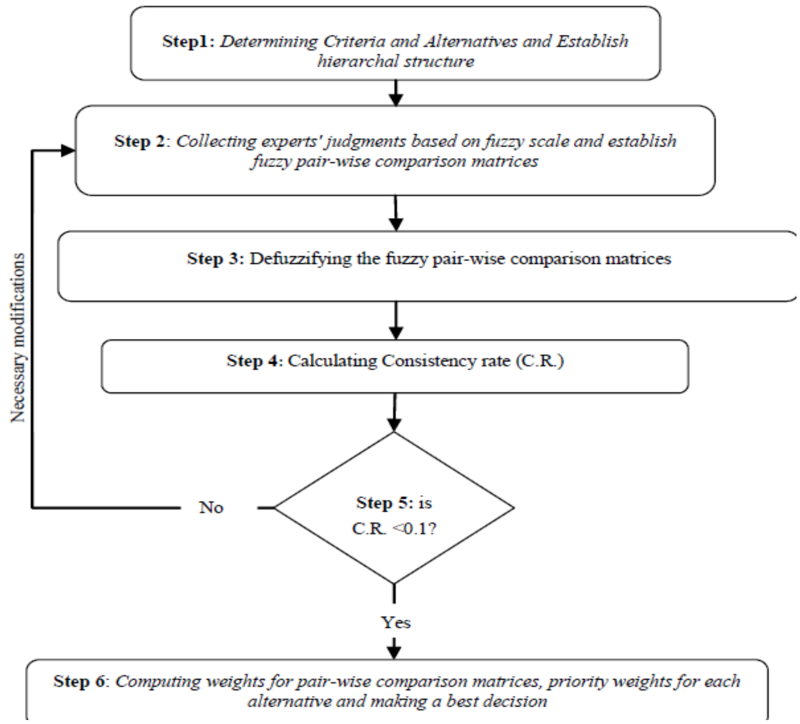

Fig 1. The proposed methodology based on fuzzy AHP

$$u_{\tilde{A}}(x) = \begin{cases} \dfrac{x-l}{m-l} & l \leq x \leq m \\ \dfrac{u-x}{u-m} & m \leq x \leq u \\ 0 & x \prec l \ \text{ or } \ x \succ u \end{cases} \tag{1}$$

$$\begin{aligned} \tilde{A} + \tilde{B} &= (l_1 + l_2,\ m_1 + m_2,\ u_1 + u_2) \\ \tilde{A} - \tilde{B} &= (l_1 - u_2,\ m_1 - m_2,\ u_1 - l_2) \\ \tilde{A} * \tilde{B} &= (l_{1*}l_2\ ,\ m_{1*}m_2,\ u_{1*}u_2) \\ \tilde{A} / \tilde{B} &= (l_1 / u_2,\ m_1 / m_2,\ u_1 / l_2) \\ k\tilde{A} &= (kl_1, km_1, ku_1), k > 0, k \in R \end{aligned} \tag{2}$$

The AHP method uses pair-wise comparisons and related matrix is shown in Equation (3).

$$\tilde{A}^k = [\tilde{a}_{ij}]^k = \begin{array}{c} \\ C_1 \\ C_2 \\ \vdots \\ C_n \end{array} \begin{array}{c} \begin{matrix} C_1 & C_2 & \cdots & C_n \end{matrix} \\ \begin{bmatrix} \tilde{1} & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ 1/\tilde{a}_{12} & \tilde{1} & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{2n} & \cdots & \tilde{1} \end{bmatrix}^k \end{array} \quad (3)$$

Where, $\tilde{a}_{ij}^k = (1,1,1) : \forall i = j;\ \tilde{a}_{ij}^k = \frac{1}{\tilde{a}_{ij}^k} : \forall i \neq j$.

To aggregate the experts' judgments, Buckley (1985)'s method is applied here. As is shown in equations (4-7) l, m, and u show the minimum possible, most likely and the maximum possible value of a fuzzy number, respectively. TFN Ak is defined as the following:

$$\tilde{A}_{ij} = (l_{ij}, m_{ij}, u_{ij}) : l_{ij} \le m_{ij} \le u_{ij}, l_{ij}, m_{ij}, u_{ij} \in [1/9, 9] \quad (4)$$

$$l_{ij} = \min(a_{ijk}) \quad (5)$$

$$m_{ij} = \sqrt[K]{\prod_{k=1}^{K} (a_{ijk})} \quad (6)$$

$$u_{ij} = \max(a_{ijk}) \quad (7)$$

Which aijk , shows the relative importance of criteria Ci and Cj given by expert k. The linguistic scale and underlying TFNs are illustrated in Table 1 based on Azadeh et al. (2011) and Nazari-Shirkouhi et al. (2011).

2. Experiment and Results

In this section, the proposed methodology is implemented on an actual case in Alborz province in Iran to select the best location for construction of an underground dam. Following successive droughts in the province and the benefits of underground dams in utilization of unconventional waters, the expert team suggested several options for selecting and evaluating the best location for building the underground dam Construction in the city of Taleghan. Figure 2 shows position of selected options over the city of Taleghan. Selection of the best location should be done based on criteria in such a way that all important technical factors are considered. The best location for underground dam construction can provide appropriate amount of water for agriculture in this region. The proposed methodology is implemented in this study area based on following steps:

Table 1

The linguistic scale and underlying TFN

Fuzzy number	Linguistic scales	Scale of fuzzy number
$\tilde{1}$	Equally important	(1, 1, 1)
$\tilde{3}$	Weakly important	(2, 3, 4)
$\tilde{5}$	Essentially important	(4, 5, 6)
$\tilde{7}$	Very strongly important	(6, 7, 8)
$\tilde{9}$	Absolutely important	(7, 8, 9)
$\tilde{2}, \tilde{4}, \tilde{6}, \tilde{8}$	Intermediate values ($\tilde{x}$)	(x- 1, x, x+1)
$1/\tilde{x}$	Between two adjacent judgments	(1/(x+ 1), 1/x, 1/ (x- 1))

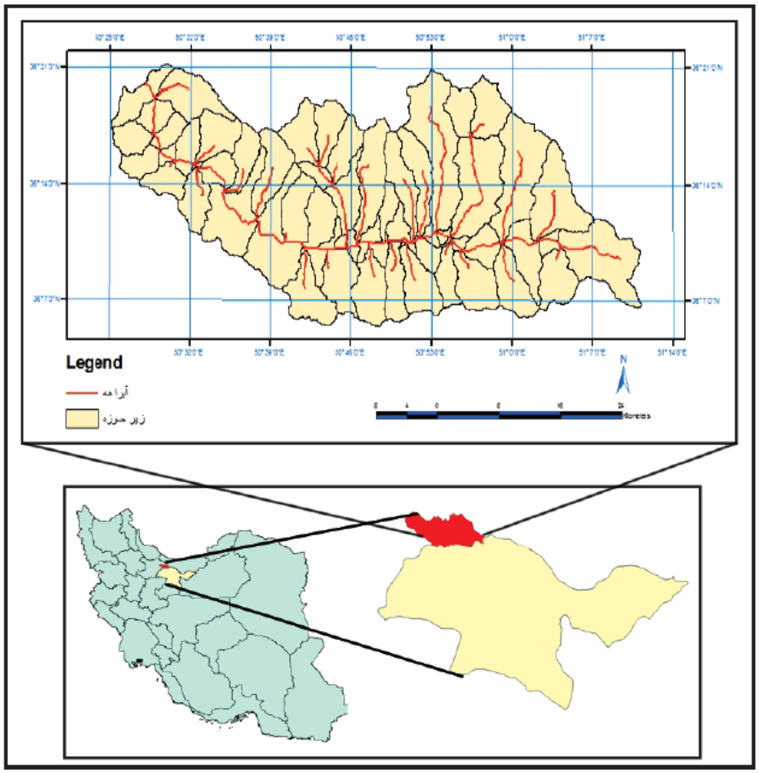

Fig 2. The site location

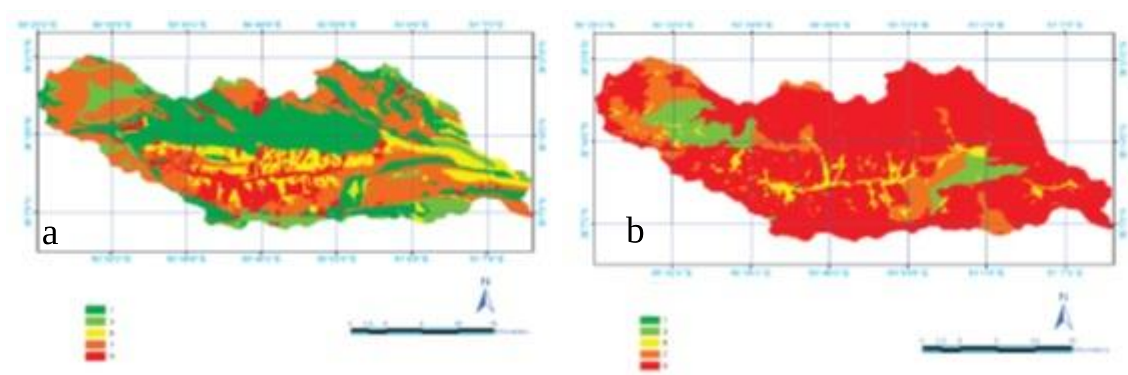

Fig 3. a) Suitable places for dam construction (Green is the best and Red is the worst) b) Geology map for the site area

Step1: ***Determining criteria and alternatives along with establish hierarchal framework***

The criteria and alternatives should be able to describe the existing difficult decision problem. Thus, considering these criteria and alternatives are very important for the decision makers' team in selecting the best location for underground dam construction.

The selected criteria according to the methodology of studying the physical specifications are as follows: bed width, utilization land area, distance to utilization location, bed slope, wall material which are extracted from the topographical maps. The, data are evaluated by experts and field studies to ensure the precision of data. After final approval, the proposed methodology is used to select the best location of project and its priorities.

Each criterion used for priority setting of a location has optimal values and conditions which should be met. For the slope, if it is high, it causes ejection of reserved water in the reservoir and thus water accumulation on its surface which, in turn, leads to subsequent problems. On the other hand, very low slope causes that there is a long distance when the reserved water is transferred and when it is transferred from the depth to the bed. Therefore, the best slope for selecting an option is about -12% (Nilsson, 1988).

After reviewing the literature related criteria, the experts' team considered eight candidate locations to evaluate with regard the expert's judgment who had worked in related field. Finally, the eight candidates are Goor choopan (Alternative 1), Khezr (Alternative 2), Bayaz (Alternative 3), Tezerj (Alternative 4), Uderj (Alternative 5), Joz (Alternative 6), Givdari (Alternative 7), and Dahaneh abolfazl (Alternative 8). The position of eight candidates over the city of Taleghan and Alborz province are shown in Figure 2.

After determining the criteria and alternatives, decision makers will setup hierarchical structure. The hierarchical structure should be able to break the existing complex decision problem into manageable components of different layers/levels (Nazari-Shirkouhi et al., 2011). The selected criteria can determine the levels of hierarchical structure. Level #1 (target level) addresses target (selecting the best location for underground dam construction). Level #2 (criterion level) addresses different factors impacting on locating decisions for underground dam construction. In the present paper, five criteria are considered. Finally, the latter level usually consists of alternatives. Different levels of the hierarchy structure for locating the underground dam construction are sketched in Figure 3.

Step 2: ***Collecting experts' judgments based on fuzzy scale***

Because the problem of locating underground dam construction can be modelled based on expert's judgment, experts play an important role on the reliability and accuracy of evaluating locations of underground dam construction. In this case study, the project manager decided to consider the problem of underground dam construction depending on the judgments by seven experts.

The sample questionnaire (see Nazari-Shirkouhi et al., 2011) is applied to find the weights of the criteria using experts' judgments in the form of fuzzy numbers shown in Table 1. According to the linguistic scale, underlying TFN in Table 1 and equations (4-7), the fuzzy decision matrix for criteria with respect to goals are achieved from a questionnaire filled by experts. Then, the fuzzy decision matrices are converted to fuzzy numbers in a way explained in Azadeh et al. (2011) and Nazari-Shirkouhi et al. (2011). Table 2 shows the aggregated fuzzy decision matrix of criteria (level 2).

Step 3: ***Defuzzifying the fuzzy pair-wise comparison matrices***

After making the fuzzy matrices for all levels, the matrices are defuzzified. Using equations (8-9) and setting α and μ to 0.5, the final defuzzified matrix (Table 2) is shown in Table 3.

Step 4: *Calculating Consistency rate (C.R.)*

The consistencies of fuzzy judgment matrices are evaluated using equations (12- 13). Equation (11) is used to determine the maximum eigenvalue (max λ). After solving maxλ equals to 5.1703.

Step 5: is *C.R.* <0.1?

The results indicate that C.R. is lower than 0.1 and the decision matrix for the second level of the hierarchical structure is consistent. The C.R.s of all the matrices are below 0.1 which show their consistency.

Step 6: ***Computing weights for pair-wise comparison matrices, priority weights for each alternative and making a best decision***

After solving equation (14), weights of the five criteria in level 2 (W) are shown in Table 4.

The local weights of the alternatives are calculated using equation (14). The final weights of all alternatives are shown in Table 5. The final weights of the alternatives using data of Table 5 are as follows: 0.0127, 0.0139, 0.0126, 0.0031, 0.0099, 0.0025, 0.0046, and 0.0039 for Al1 to Al8 , respectively. According to results, the first alternative has the highest weight and is the most proper location according to the experts' judgment in the fuzzy environment. "Goor Choopan" and "Dahaneh abolfazl" locations are suggested as the first and last options, respectively.

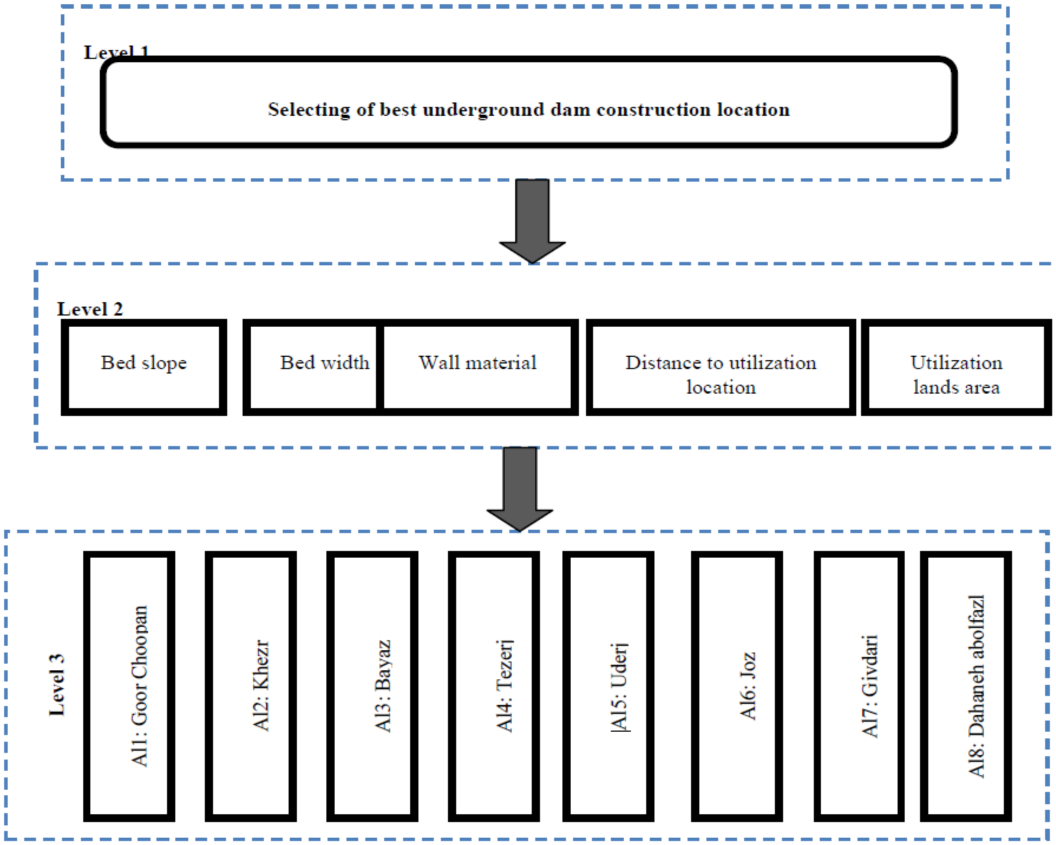

Fig 4 Hierarchical structure for underground dam construction

3. Validation and Verification

For validation and verification of results, the pair-wise comparison matrices are run in the crisp state (standard AHP). The local weights of criteria in the second hierarchical level (AHP) are shown in Table 6. As we can see in Table 4 and Table 6), the criterion 1 (Bed slope) and the criterion 4 (Distance to utilization location) are the most important and least important criteria according to their weights in both AHP and Fuzzy AHP methods, respectively. The final weights of all alternatives (AHP) are shown in Table 7. The results of two runs (fuzzy AHP and AHP) have been compared and shown in Table 8.

Table 6

The weights of five criteria of level 2 (AHP)

Criteria	Bed slope	Bed width	Wall material	Distance to utilization location	Utilization lands area
Weight		0.22	0.16	0.12	0.06

Table 7

Summaries of results (AHP)

Criteria	Weights for level 2	Weights for level 3							
		Al1: Goor Choopan	Al2: Khezr	Al3: Bayaz	Al4: Tezerj	Al5: Uderj	Al6: Joz	Al7: Givdari	Al8: Dahaneh abolfazl
Bed slope	0.41	0.17	0.20	0.13	0.02	0.10	0.09	0.17	0.09
Bed width	0.22	0.10	0.07	0.09	0.23	0.19	0.13	0.03	0.12
Wall material	0.16	0.20	0.13	0.06	0.14	0.20	0.07	0.09	0.04
Distance to utilization location	0.12	0.20	0.17	0.20	0.17	0.10	0.04	0.17	0.17
Utilization lands area	0.06	0.09	0.06	0.02	0.14	0.20	0.07	0.10	0.04
Final Weight		0.167	0.170	0.092	0.112	0.161	0.094	0.111	0.088

Table 8

Comparison of ranks between AHP and Fuzzy AHP

Alternatives	AHP		Fuzzy AHP	
	Weight	Rank	Weight	Rank
Al1: Goor Choopan	0.111	3	0.0066	3
Al2: Khezr	0.088	6	0.0029	6
Al3: Bayaz	0.112	5	0.0099	5
Al4: Tezerj	0.161	8	0.0126	8
Al5: Uderj	0.17	1	0.0048	2
Al6: Joz	0.092	2	0.0132	1
Al7: Givdari	0.167	7	0.0127	7
Al8: Dahaneh abolfazl	0.094	4	0.0041	4

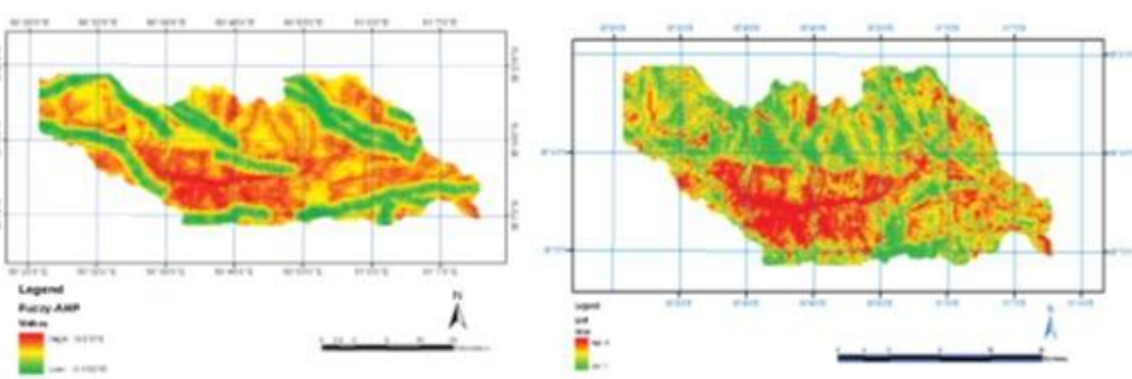

Fig 5. a) Final map based on Fuzzy-AHP methodology b) Final map based on AHP methodology

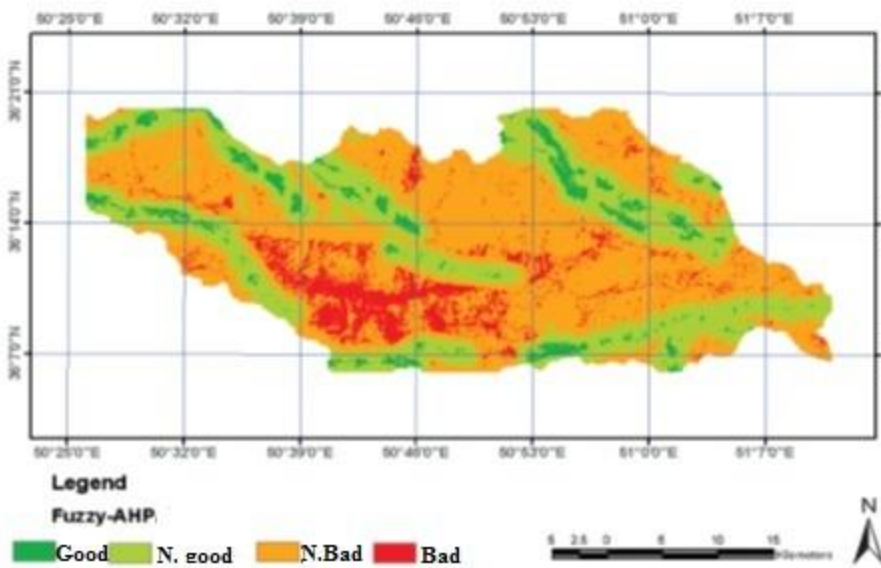

Fig 6. Final map based on Fuzzy-AHP methodology after changing to the qualification data

4. Conclusion

In present study, a holistic fuzzy AHP approach as a multi criteria decision making tool is proposed for optimal site selection of underground dam construction. Incorporating real life ambiguities and uncertainties, problem become highly complex and non-linear which is need a robust methodology to find the optimal response. The main criteria are included: bed slope, bed width, wall material, distance to utilization location, and utilization lands area. Eighth different alternatives for the location underground dam construction were considered in an actual case study. Based on the goal of underground dam construction, the proposed hierarchical structure may vary slightly. Finally an experiment and actual case has been conducted to apply the proposed methodology in evaluating and selecting the best underground dam construction location as a case by using judgments of six experts who had worked in the underground dam construction field and then the results were represented. As a result of the empirical study, the fuzzy AHP is obtained as practical and holistic approach for ranking the candidates in terms of their overall performance regarding multiple criteria. In this case, fuzzy AHP provides a very effective and efficient decision-making tool to rank underground dam construction locations. It is expected that the present paper will serve as guideline for future studies and applications of locating in underground dam construction.

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