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Comparison of FAHP and FANP Decision-Making Methods in Determining the Appropriate Locations for Constructing an Underground Dam for Water Harvesting

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Abstract
The recent droughts in Iran made a decline in groundwater table and the migration of villagers to cities was hindered supplying drinking water for the current population. Therefore it should be considered as an important issue. In this regard, it is possible to achieve this goal by constructing underground dams that recently have been suggested to replace by medium and small overland dams. The aim of this study was to compare and investigate the efficiency of multi-index decision-making methods, that is identified as Fuzzy Analytical Hierarchy Process (FAHP) and Fuzzy Analytical Network Process (FANP), to find an initial suitable location for constructing an underground dam in Birjand watershed catchment. The GIS information layers consist of distance to waterways, the geology of the area, the slope of the area, distance to the floodplain, distance to villages, distance to wells, springs and qanats, land use, distance to faults and distance to roads. By using the FAHP and FANP algorithms, weights of information layers were obtained. The results of both methods showed that suitable locations for constructing underground dams are located in the vicinity of low slope waterways. The results of both methods were compared by Chi-Square Test. The result of this test showed that the FAHP and FANP models are significantly different and the FANP method is more accurate.

Keywords: Underground dam, FAHP, FANP, Chi-Square Test.

1- Introduction

Sufficient water resources are one of the main factors for the development and progress of each region. Responsible authorities always try to improve the status of water resources and manage them in an optimal way. Water scarcity is one of the most important problems in the countries of the arid and semi-arid regions of the world including Iran. However, these limited resources also have not the appropriate spatial and temporal distribution. On the other hand, the country's development has led to an ever-increasing need for water in different parts of the country, which highlights the importance of water as the main factor of life and production in the country more than ever (Zarghami et al., 2011).

The coping strategies of water shortage are summarized in two strategies of the proper management of water resources and harvesting from new sources of water. In our country, due to geographic and climatic reasons, improving management of available water resources will have better and faster results (Kheirkhah Zarkesh et al. (2008). Underground dams are structures that block the natural flow of groundwater and accordingly the creation of underground water resources (Onder & Yilmaz, 2005). Locating of underground dams is a very complex process and geological, geomorphological and hydro-geological factors play a decisive role in it (Kheirkhah, 2008).

The advantages of constructing such dams consist of preventing water loss due to reduced evaporation and transpiration, especially in warm and dry areas, preventing water pollution from natural and human pollutants, preventing damage to soil resources and diminution of land use change due to its underground nature , reinforcement of underground aquifers and use of water resources which are based on time requirements (Vanrompai, 2003).

Due to the fact that in determining the optimal site of underground dams, the number of effective indexes are varied and numerous, and moreover because these indexes are not only in form of quantitative and qualitative indexes but also with different dimensions, prioritizing the dam construction sites without the help of multi-index decision-making methods is impossible. In this regard, it has been tried to prioritize and weight these index in order to use in models and also determine a proper index for constructing dams by surveying various experts in water section and studying previous research.

Studies on the construction of underground dams have been carried out in different parts of Iran and other countries. Kheirkhah (2008) has used hierarchy analytical method for prioritizing suitable places of constructing underground dams in the northern skirts of the Karkas mountain of Natanz. In another accomplished research by Chezgi et al. (2009), they sought to find the best points for the construction of a groundwater dam in the west of Tehran province. They also expressed the necessity of using underground dams after preliminary evaluations and determining the appropriate index. In addition, they prioritize the region based on the AHP method and eventually introduced 27 points as suitable areas for the construction of the underground dam. Slope and geology are considered as the most important factors. They also concluded that the best points for constructing underground dams are rivers with 3 and 4 grades.

Esavi et al. (2010) in a study comparing two methods of AHP and FUZZY-AHP in locating a groundwater dam in Taleghan Watershed catchment. In this research, geological layers, slope, waterway, villages' location, fault location, and vegetation index was used. The results showed that out of 56 outlets of sub-watershed catchments, 26 points in the AHP method and 15 points in the FUZZY-AHP method overlaps with suitable and accessible areas. The results showed that FUZZY-AHP method has more flexibility and higher capability in the determination of suitable areas for dam construction.

Forzieri et al. (2008) in research investigated the method of selecting suitable sites for the construction of small underground dams in arid areas with a case study was conducted in the Kidal region in Mali country. Selecting the right points in three phases involves identifying the points through the interpretation of satellite images and large-scale maps, qualitative selection of points based on functional and geomorphic characteristics, and third stage of prioritization of points was done by multi-index decision making. The result showed that this method is a general method for determining the suitable points for constructing underground dams and the interpretation of satellite images and large-scale maps are valuable tools for primary ground analysis and tectonic characteristics. Reports showed that limited studies have been conducted so far to compare two new methods of FAHP and FANP to determine the appropriate areas for the construction of an underground dam with the aim of supplying drinking water to adjacent villages and preventing them from migrating to cities.

Jamali et al. (2014) aimed to develop and test a methodology to locate suitable sites for construction of subsurface dams using spatial multi-criteria analysis (SMCA) in the northern parts of Pakistan. For the study, spatial data on geology, slope, land cover, soil depth and topographic wetness index (TWI) was used. Two weighting techniques, i.e. the analytic hierarchy process (AHP) and the factor interaction method (FIM), were employed and compared. The sensitivity analyses suggested that AHP was a more robust weighting technique than FIM and that land cover was the most sensitive factor. The methodology presented here shows promising results and could be used in early planning to locate suitable sites for construction of subsurface dams.

Jamali et al. (2018) in a study aims at identifying suitable sites for underground dams using a spatial multi-criteria evaluation (SMCE) for water supplies in an arid watershed in southwestern Iran. Specific constraints and three groups of criteria were used in developing a spatial decision model. Constraints included slope, fault, land use, and geology. A criteria tree was designed and standardized using Boolean logic and fuzzy membership on factors. Factors were weighed by both ranking and direct methods. Finally, the composite index map (CIM) was used to identify the three best sites. With valley shape consideration, Site2 was the most suitable for construction of a subsurface dam. Interpretation of valley profile, optimum decisions on subsurface dams, and multicriteria for site selection can be used in water resource planning.

2- Materials and methods:

The watershed catchment of Birjand plain is shown in figure (1) as the most important southern plain of Khorasan in terms of population concentration, urbanization status, the concentration of economic and military activities placed 33 percent of South Khorasan population with a population of 210,000 people. This plain is bounded to the plains of Asadabad and Musaviyeh hole from the north and Mokhtaran plain from the south and Sarbisheh plain from the east (Keshavarz, 2013).

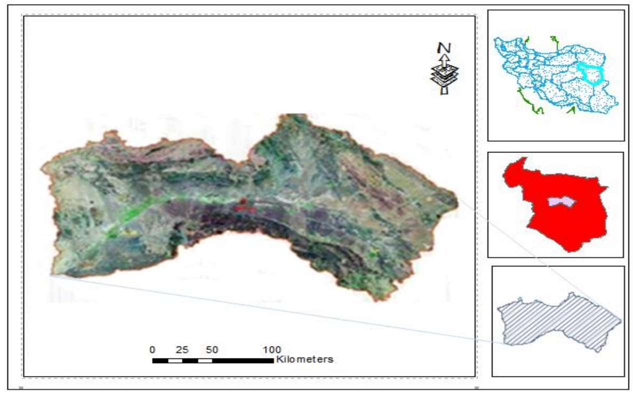

Fig.1. Birjand watershed basin

Since different metrics have different measurement scales, therefore, for their alignment and overlap, their raster data layers must also scale the same. The fuzzy membership functions are used for this purpose. Fuzzy membership functions are functions that map each of the raw data from the classical complex to a fuzzy value of the fuzzy set [0,1] (Koorepazan Dezfooli, 2008). After making raster layers, the decision parameters transform to fuzzy members in the Arcgis9.3 environment. In order to make continuous data to fuzzy ones, fuzzy membership functions were used. These functions assign each member of the set a value criterion from zero to one ([0,1]). Due to the ascending, descending or ascending- descending nature of each criterion, a suitable fuzzy function was chosen to make that criterion as a fuzzy one. The index for which the nature of data was discrete, became fuzzy discretely (Azar et al. 2008).

Each channel, in accordance with its own level, has a role in the process of collecting rain, so that as the river level rises, in other words, its capacity and size increases, its contribution to the production and transfer of runoffs becomes higher and more valuable in locating (Sadeghi et al. 2002). In figure (2), the fuzzy map of the distance from the waterways has been presented. The points that have a shorter distance with the center of the river are of greater value. With the more distance from the center of the waterway, its pixel value decreases. In order to make this criterion to a fuzzy one, a Z-shape function was used.

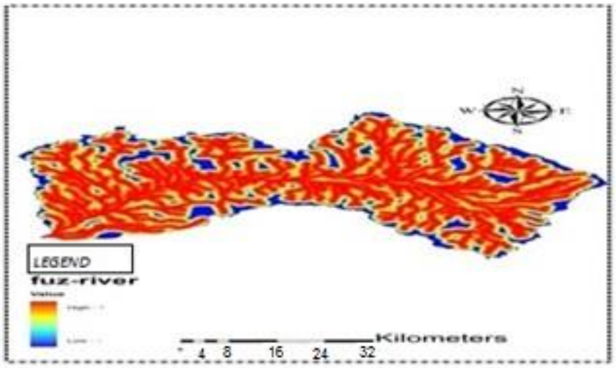

Fig.2. The fuzzy map of distances to the reaches

Geology has a great influence on the quality of water. Geological units, depending on the type, have a great influence on the permeability of the dam reservoir. For this purpose, geological units with a detrimental effect on water quality will have the lowest pixel value (Esavi, 2012). Some of these units include domes and salt plains, Marley sediments of evaporated sediments (such as gypsum and sulfate) Ngm (lichen, siltstone and evaporated marl), Q1s (deposits of massive movement or lower quaternary of mountains), Q2s (deposits of massive movement or upper quaternary of mountains), gy1 (the highly evaporative lower marl) and gy2 (lichens, silt-stones and highly evaporated upper marl) were considered due to their characteristics of low permeability, fine-grained and high salts as inappropriate. Deposits including (Q3al today's bedrock deposits), (Q2af cone deposits), Qt4 or T (presidio deposits of Troy's war) due to proper penetration and high porosity and high costs and also the lack of high-level salts was determined appropriate.) This layer became fuzzy discretely (Fig. 3).

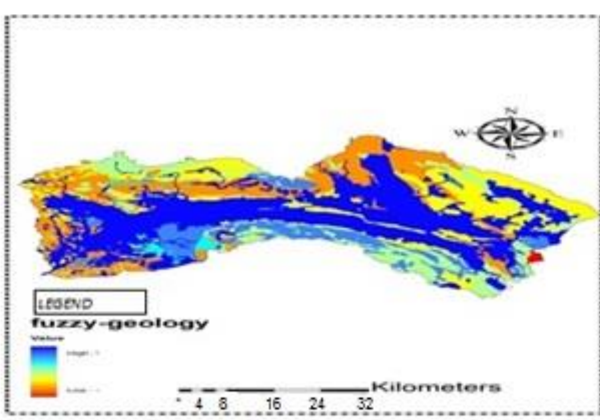

Fig.3. The fuzzy geological map

The conducted investigations show that the best slope for the construction of a groundwater dam is about 0.2 to 8 percent. By using the map of area topography and providing a digital elevation model, the map of the plain slope was obtained. In this study, the slop of 2-8% has the highest degree of membership. For a slope higher than 30 degrees belong the 0 membership. It should be noted that a trapezoidal membership function was used in order to make this parameter fuzzy. (Fig. 4)

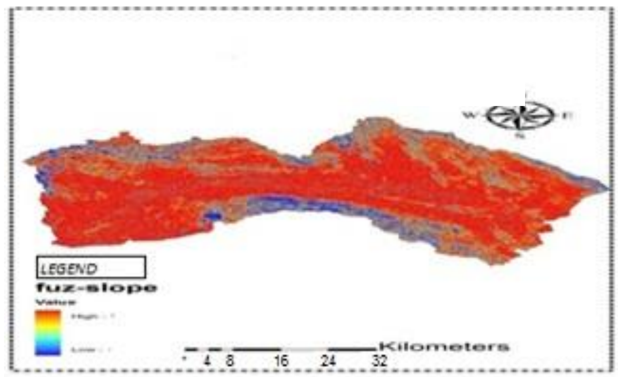

Fig.4. The fuzzy map of basin slope

If the place of construction has a short distance to the fault, then it may break down and cause water to escape over time and with the occurrence of even small earthquakes. By providing a map of faults limitations, the points near to the fault have the lowest score, and the membership degree increases by going away from the fault. The membership function used to fuzzy this criterion is the S-shape function (Fig. 5).

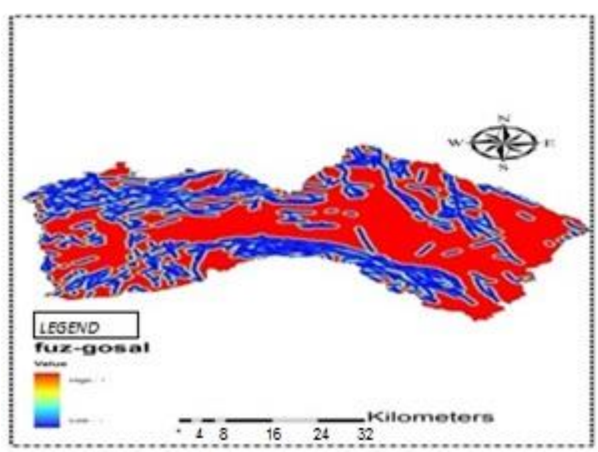

Fig.5. The fuzzy map of distances to faults

After providing a layer of distance from villages, a limit of 200 m has been considered around the village based on experts' view. After this section, the nearest distance to the village achieved the highest score. This type of scoring is considerable economically because of the costs of water transmission increase by the increase of the distance significantly. A trapezoidal function is used to make this parameter fuzzy (Fig. 6).

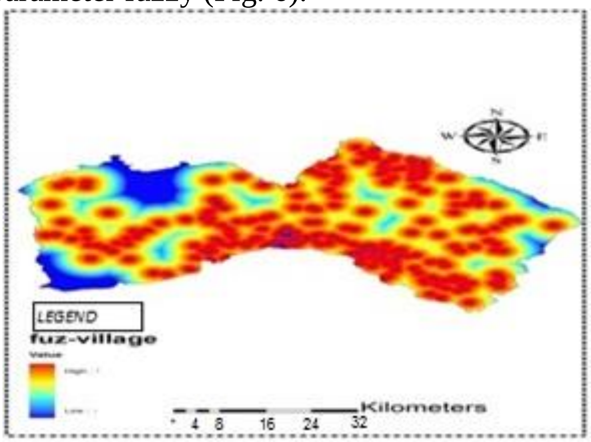

Fig.6. The fuzzy map of distances to villages

One of the most important challenges facing underground dams is the need to provide adequate water for them. One way to solve this problem is intervening information about flood zones in decision-making related to the location of underground dams. By providing a map of distance from flood zones, points with the lowest distance from these zones will have the highest degree of membership. To provide this fuzzy layer of this criterion, the Z-SHAPE function has been used (Fig.7).

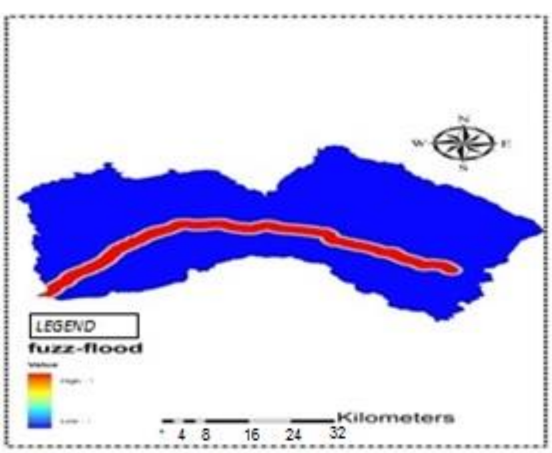

Fig.7. The fuzzy map of distances to flood plain Zones.

Landuse factor can be significant socially and economically. Since the construction of an underground dam, e.g. in the farming land, can create problems both socially and economically. In order to provide a fuzzy map of these criteria, the discrete method has been used (Fig.8).

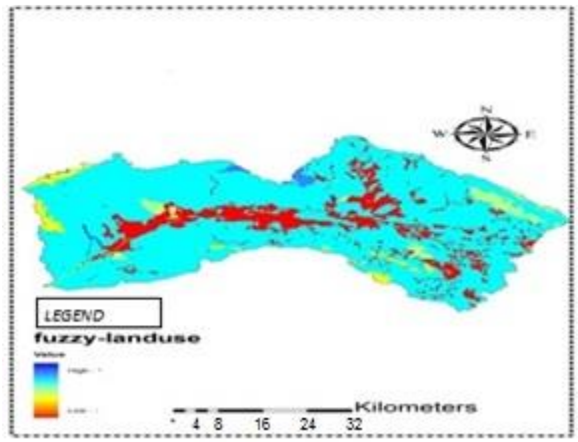

Fig.8. The fuzzy map of land uses

Due to the prohibition of the construction of any structures, the roads limitation according to experienced experts is considered as 250 meters and the lowest score was allocated to this section. After that, the nearest distance to this area gained the highest score. This score decreased by getting away from the road. the trapezoidal function has been used for making this criterion fuzzy (Fig.9).

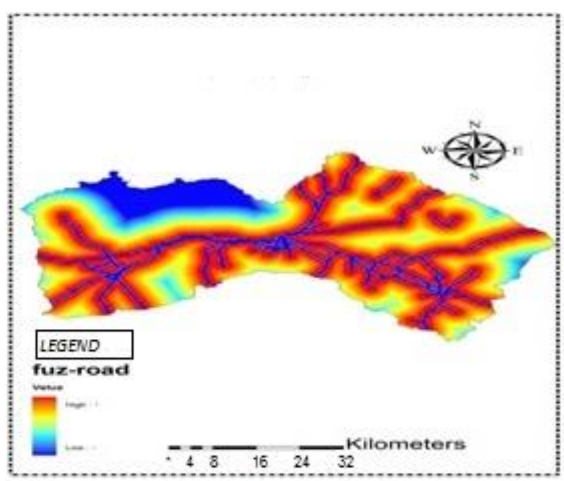

Fig.9. The fuzzy map of distances to the roads

It is socially important that the place for the construction of underground dams has not any intersection with the location of the wells, springs, and aqueducts. The existence of a groundwater dam in the upper part of the aqueducts can reduce or stop its drainage, which happens due to the decrease in the surface of the aqueduct watershed catchment. But the presence of a dam at the bottom of the aqueduct can lead to an increase in the level of subsurface and underground water in that area and increases the drainage of the aqueduct. Similarly, the effects of underground dams on wells and springs can also be evaluated. To prepare a fuzzy map of these three factors, also a trapezoidal function has been used (Fig. 10, 11, 12).

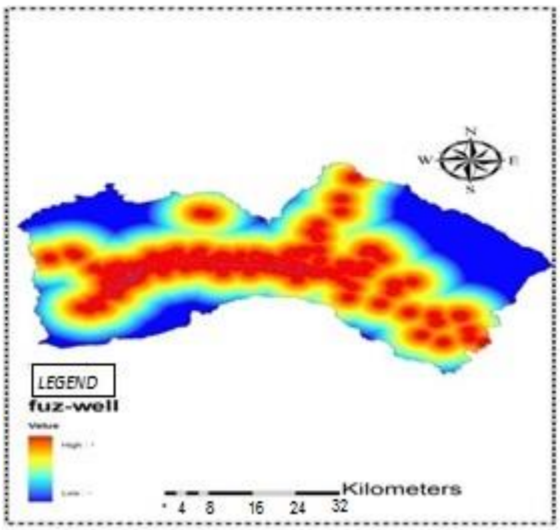

Fig.10. The fuzzy map of distances to wells

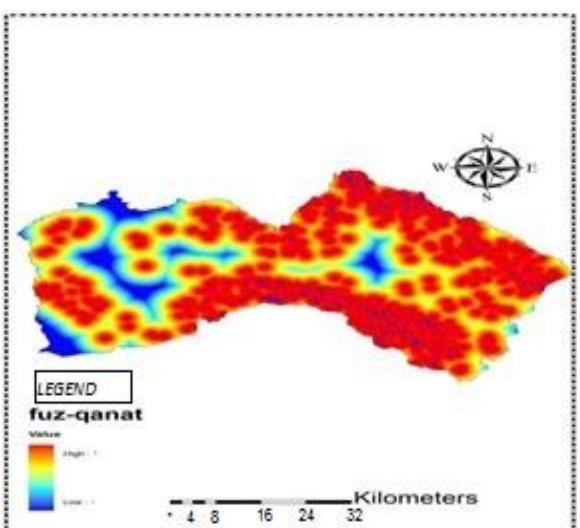

Fig.11. The fuzzy map of distances to qanat.

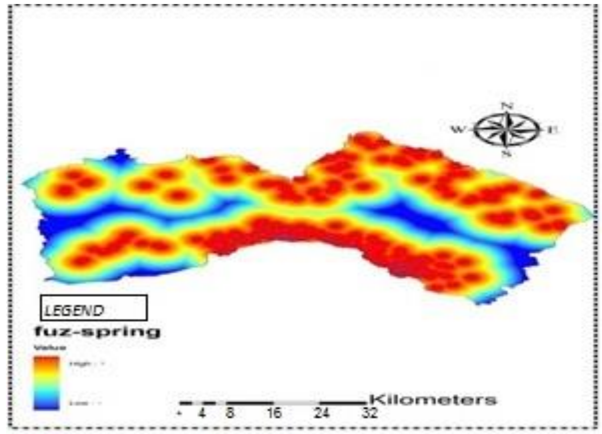

Fig.12. The fuzzy map of distances to springs

Used Methods

a. Fuzzy Hierarchy Analytical Process:

In this method, the decision maker can compare pairwise elements of each level in the form of triangular or trapezoidal fuzzy expressions (Saaty, 1980). In this study, triangular fuzzy numbers were used. Considering that the indexes for distance to road, slope, and distance to well, springs and aqueduct and distance to rural areas have an ascending-descending value, trapezoidal membership function was used to realize the purpose of the research to make them fuzzy. Distance to waterways and distance to flood became fuzzy by using a Z shape membership function because they are descending and by increasing the distance, their desirability reduces. The criterion of distance from faults is also ascending and became fuzzy by using an S-shape function. The indexes of geology and land use are discrete indices and fuzzy values have been assigned to them.

The steps to do this are as follows:

The first step- after preparing a questionnaire, different experts' opinions about the importance of each criterion in determining the target goal is collected and a pairwise matrix was constructed.

The second step- To overcome the problem of inconsistency in personal judgments of experts, compatibility coefficient of Saati (CR) was used which gained the division of compatibility index (CI) to randomize index (RI). If this coefficient is equal or less than 0.1, the compatibility of judgments is acceptable. Otherwise, the judgments should be revised (Zebardast, 2003).

Third Step - Using Table 1, the pairwise matrices' scores of the experts are transformed to triangular fuzzy numbers, each representing a linguistic variable and fuzzy pairwise matrices was obtained as (1) (Buckley, 1985).

$R^k = [r_{ij}]$ (1)

Fourth Step - Based on the maximum Lambda method proposed by Csutora and Buckley (2001), the fuzzy weight of the decision-making index has been calculated based on the following procedure:

Using Alpha Cutting: Considering R^k_a and R^k_c Matrix α=0 and R^k_b matrix α=1

$$\alpha = 1 \rightarrow R^k_b = (r_{ij})^k_{b'}, \alpha = 0 \rightarrow \{R^k_a = (r_{ij})^k_{a'} R^k_c = (r_{ij})^k_c \quad (2)$$

In which:

Number of experts: K

The minimum, center and maximum points of a triangular fuzzy are respectively. a, b and c.

Based on the method of AHP, In each of the matrices of R^k_b, R^k_a, R^k_c weights have been estimated.

$$W^k_b = (w_i)^k_b, w^k_a = (w_i)^k_a, w^k_c = (w_i)^k_c \quad i = 1,2,\dots,n \quad (3)$$

Constants of M^k_a and M^k_c are estimated according to the following formulas.

$$M^k_a = \min\{\frac{w^k_{ib}}{w^k_{ia}} | 1 \le i \le n\}$$

$$M^k_c = \max\{\frac{w^k_{ib}}{w^k_{ic}} | 1 \le i \le n\} \quad (4)$$

Then, the upper and lower limits of the fuzzy weights were calculated as follows.

The upper and lower bounds of the weights matrix are as follows.

$$w^{*k}_a = (w^*_i)^k_{a'} \quad w^{*k}_c = (w^*_i)^k_c \quad i = 1,2,\dots,n \quad (5)$$

The upper and lower bounds of the weight matrix are as follows:

$$w^{*k}_a = (w^*_i)^k_{a'} \quad w^{*k}_c = (w^*_i)^k_c \quad i = 1,2,\dots,n \quad (6)$$

By combining w^{*k}_c, w^{*k}_b, w^{*k}_a, fuzzy weight matrix for K[th] expert is as follows:

$$w^k_a = (w^{*k}_{ia}, w^{*k}_{ib}, w^{*k}_{ic}) \quad i = 1,2,\dots,n \quad (7)$$

In order to combine various experts' comments, a geometric mean of fuzzy weight has been used.

$$w = \left(\prod_{k=1}^{k} w^k_i\right)^{\frac{1}{k}} \quad (8)$$

In which:

The combined fuzzy weight of the i index from the k expert: W

The fuzzy weight of i index from k expert: w^k_i

The obtained fuzzy weightage is non-fuzzy and in the classical form using the following equation.

$$cc_i = d(w_i, 0) / d(w_i, 1) + d(w_i, 0) \quad , \quad i = 1,2,\dots,n$$

$$0 \le cc_i \le 1 \quad (9)$$

$$d(w_i, 0) = \sqrt{1/3((w_{ia} - 0)^2 + (w_{ib} - 0)^2 + (w_{ic} - 0)^2)} \quad (10)$$

$$d(w_i, 1) = \sqrt{1/3((w_{ia} - 1)^2 + (w_{ib} - 1)^2 + (w_{ic} - 1)^2)} \quad (11)$$

In which:

d (w_i, 0) and d (w_i, 1) are measured intervals between the two desired fuzzy numbers. In fuzzy layers, the index for each of the pixels (options) obtains a value between 0 to 1 [1,0] in which the membership degree is the raw value of the related index in that pixel. In each pixel, the calculated weight of each pixel, the calculated weight related to each index is multiplied with the membership degree of considered index related to that pixel in order to obtain the real value of each index. To obtain the final overlap and the desired map, a fuzzy integral operator was used, because the results of the other operators such as fuzzy multiplication and gamma did not match much with reality. Table (1) Fuzzy numbers corresponding to the qualities variables (Lu li et al 2009).

Table 1. Fuzzy numbers corresponding to the qualities variables

verbal variables	Positive triangular fuzzy numbers	Inverted positive triangular fuzzy numbers
Equal impotency	(1,1,1)	(1,1,1)
medium impotency	(1,2,3)	(1.1,3.1,2)
liberated impotency	(4,3,2)	(1.1,4.1,3.2)
liberated impotency	(5,4,3)	(1.1,501,4.3)
liberated impotency	(6,5,4)	(1.1,6.1,5.4)
liberated impotency	(7,6,5)	(1.1,7.1,6.5)
liberated impotency	(8,7,6)	(1.1,8.1,7.6)
liberated impotency	(9,8,7)	(1.1,9.1,8.9)
liberated impotency	(9,9,9)	(1.1,9.1,9.9)

Fuzzy Network Method Algorithms

The steps in this method are:

1. Making the model and structure of the problem:

The problem should be clearly expressed and broken down into a logical system. The mentioned structure can be used in terms of decision makers and methods like brainstorming or other appropriate methods.

2. Pairwise Comparison Matrices and Priority Vectors

At this stage, all the main factors and their sub-index must be compared in pairs, which should be in line with their effect. It is better to use questionnaires and question from experts familiar with the problem and in the form of a series of pairwise comparisons. In fact, the difference between the FANP method and other decision-making methods is at this stage. In this model, not only clusters effect on elements and elements on option and option on elements but even elements effect on each other and other elements of clusters. In other words, each element has the capability of affecting other elements.

3. Supermatrix Formation

The supermatrix can limit the coefficients to calculate all priorities and as a result of the combined effect of each element on other elements in interacting. When a network contains index and options, the present matrix approach provided by Saati and Takizawa can be implemented to encounter with correlations of elements in a system. They express that for obtaining the general priorities in a system with interacting effects of vectors, the priorities should be entered in particular columns of the matrix which called here as supermatrix. In fact, a super matrix is a partitioned matrix, each of which shows the relationship between the two groups in a system.

4. Choosing the best option

If the composed super matrix in the previous step covers all network, the priority weights in the options column in a normalized super matrix can be found. On the other hand, if a supermatrix contains only parts that are interconnected, more computations are needed to achieve the general priorities of the options. In order to calculate the final coefficient, three super matrices must be computed. Non-weighted supermatrix is the primary results put together. The weighted supermatrix that is normalized in the previous stage and the limit super matrix in which all the numbers and values of the weighted supermatrix weighted in a constant number to create a similar coefficient for each element and option. Finally, the option with the highest priority is known as the preferred option.

3- Discussion and Results

The purpose of this study was to investigate and compare FAHP and FANP methods in determining the suitable sites for the construction of groundwater dam in the Birjand watershed catchment. In following, its results are presented:

According to the results of the questionnaires submitted to the experts, these results became triangular fuzzy numbers. Then the fuzzy weight of the index is calculated with the FAHP method and eventually became non-fuzzy. The results were presented in Table (2).

Table2. weight of indexes in FAHP

Index name	Classic weights
Distance to the reaches	0.183
Geology	0.151
Basin slope	0.155
Distance to the geological faults	0.121
Distance to the villages	0.092
Distance to the flood plain areas	0.070
Land use	0.062
Distance to the roads	0.0570.070
Distance to the wells	0.05
Distance to qanat	0.039
Distance to the springs	0.032

Weights of the index in FAHP

As you can see, the highest weight is allocated to the distance from the waterways, and then the geological of region criterion is ranked second. The final obtained map is shown in Figure 13. It should be noted that in order to overlap, the AND fuzzy actor has been used.

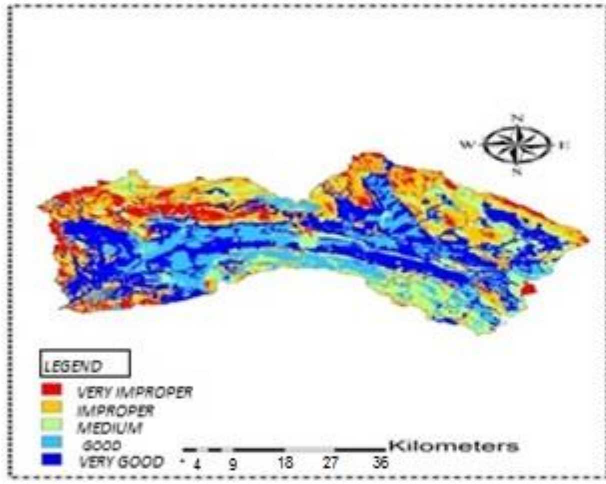

Fig 13. final zoned map of the basin by FAHP method

The variation of the index and the percentage area for each of the different classes of the talent region map is presented in Table (3). According to zoning Map (Fig. 13) areas located on a very good level are located mostly around the waterways, due to it is assigned a higher weight by the experts. The northern areas of the watershed catchment, which is unsuitable for the construction of underground dams are classified in an inappropriate or very inappropriate level.

Table3. variation of indexes and percentage of areas of each layer by FAHP method.

Areas percentages	28.53	21-23	18.10	21.43	10.72
layers	Very good	good	Medium	improper	Very improper

Table 4.weight of indexes in FANP

Index name	Classic weights
Distance to the reaches	0.140
Geology	0.100
Basin slope	0.192
Distance to the geological faults	0.131
Distance to the villages	0.045
Distance to the flood plain areas	0.092
Land use	0.093
Distance to the roads	0.051
Distance to the wells	0.057
Distance to qanats	0.048
Distance to the springs	0.042

It is noted that in this method, the slope of the region has the highest weight and then the distance to the waterway is in the next position. The final map obtained from this method is shown in figure (14).

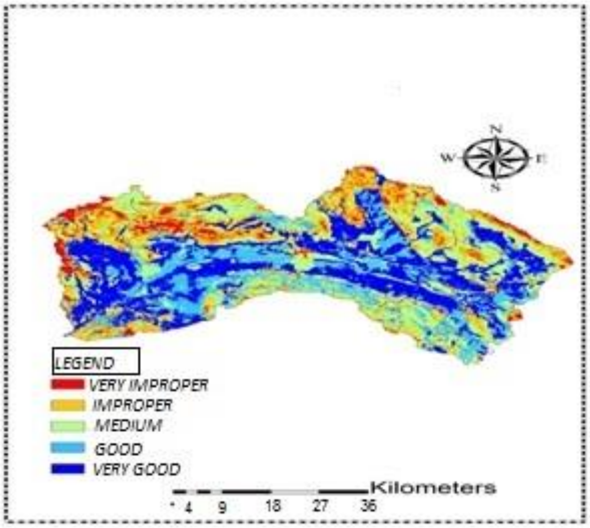

Fig 14. final zoned map of the basin by FANP method

Indicator changes and percentages of the area of each of the different classes of the region talent map is presented in Table (5). Due to the fact that in this method two indexes of the slope of the area and the distance to the waterways had the highest weight, so they applied the most effect in the zoning map so that with the advance of the west of the watershed catchment to the east of the central regions, which includes both the drainage channels and the suitable slope for construction of a groundwater dam is widely recognized as the most suitable area.

Table5. variation of indexes and percentage area of each layer by FANP method.

Areas percentages	27.96	19.98	25.01	20.29	6.76
layers	Very good	good	Medium	improper	Very improper

The northern and southern regions of the watershed catchment have more slopes and are more frequent in terms of faults. These factors are inappropriate to use for construction of the underground dam, therefore, these areas are in the middle, inappropriate and very inappropriate.

To compare the two methods used in this study, the Chi-square test was used. To do this test, the value of the chi-square should be calculated for the maps of the FAHP and FANP methods, and it should be compared to the obtained Chi-square from the table. This table value is related to two parameters of degrees of freedom (DF) and significance level. The considered significance level in this test is 5%. In this research, the degree of freedom is equal to the difference in the number of classes of the resulting maps and multiplication in the number of compared maps minus one. Considering the degree of freedom, the level of significance is obtained as 5% of the critical value of chi-square in tables with chi-square values equal to 9.488. According to the number of pixels in each level, the value of the chi-square was calculated to be 3613, which is much larger than the value in the table, so the obtained results of the two methods are different at a significant level of 5%.

4- Conclusion

In determining the appropriate sites for the construction of underground dams, there are many indexes that their variety and multiplicity complicate the decision making and optimized site selection. The solution to this problem in this research is to use multi-index decision-making models. According to the FAHP and FANP algorithms, the zoning plan of suitable locations for the construction of the groundwater dam is obtained. The results in both methods showed that most of the areas in a very convenient level were located near the waterways. The north and south of the watershed catchment were considered to be inadequate due to the fault and slopes. Due to the field studies, the fuzzy network analysis method in which the internal relations of index and sub-indexes are considered had more accuracy.

The results of the two mentioned methods were compared by using the Chi-square test. The test showed a 5% significant difference in the results. Considering the effectiveness of multi-index decision-making methods, it is recommended that by doing more field studies and performing various tests, to improve the input information for these models to achieve a better output.

5- References

Azar A. and Faraji h. (2008). *Fuzzy management science, Iran center of water study and efficiency*, ejtema publication, second edition.

Buckley J.J., (1985). *"Ranking alternatives using fuzzy numbers", Fuzzy Sets Systems Vol. 15 (1), pp. 21-31*.

Chezgi g, Moradi h, Kherkhah M, Ghasemiand, Roostaea v y, 2009, *site determination of underground dam by elimination and GIS methods case study; western zones of Tehran city*, fifth conference in Iran science and engineering water-shed management.

Csutora R. and J. J. Buckley. (2001). *Fuzzy hierarchical analysis: the Lambda-Max method.Fuzzy Sets and Systems, 120(2) 181–195.*

Esavi v, Karami g, Alimohammadi V, Niknejad a,2012, *comparison of two different decision-making methods on-site location finding of under-ground dam in Taleghan region*, Earth science magazine, vol. 85,pp.27-34.

Forzieri, G., Gardenti, M., Caparrini, F. and Castelli, F. 2008. , *A methodology for preselection of suitable sites for surface and underground small dams in arid areas: A case study in the region of Kidal, Malia*, physics, and chemistry of the Earth 33: 74-85.

Jamali A., Randhir T., Nosrati J.,(2018), *Site Suitability Analysis for Subsurface Dams Using Boolean and Fuzzy Logic in Arid Watersheds*, Journal of Water Resources Planning and Management, Volume 144 Issue 8 - August 2018.

Jamali I., Mortberg U., Olofsson B., Shafique M., *A Spatial Multi-Criteria Analysis Approach for Locating Suitable Sites for Construction of Subsurface Dams in Northern Pakistan*, Water Resources Management November 2014, Volume 28, Issue 14, pp 5157–5174.

Kheirkhah zarkhesh, m, Naseri h, Davodi m, Salami h, (2008)*use of the analytical hierarchical method in priority location of under-ground dam construction case study northern site of Karkas mountain Natanz*, research and construction journal in natural resources 80:70-87.

Keshavarz a, Khasheae a, Najafi m, Khochek Zadeh m,2013.*proper site location for exploration well for drinking water by analytical hierarchal processes case study: Birjan watershed basin*. Water and wastewater company journal,vol.3 pp.133-142.

Koorepazan Dezfooli a, 2008, *principles of fuzzy summation theory and its application in engineering problems* Academic Jihad publication Amirkabir industrial units pub. pp.212-225.

Lu Li, Zhi-Hua Shi, Wei Yin, Dun Zhu, Sai Leung Ng, Chong-Fa Cai, A-Lin Lei .2009. *A fuzzy analytic hierarchy process (FAHP) approach to eco-environmental vulnerability assessment for the danjiangkou reservoir area, China, Ecological Modelling220, PP:3439-3447.*

Onder, H., Yilmaz, M., 2005- *Underground dams*, Journal of European Water:45-35.

Saaty, T.L., 1980. *The Analytic Hierarchy Process: Planning Priority Setting Resource Allocation*. First Edition. McGraw-Hill, New York. pp. 55-126.

Sadeghi S.H., Akbarpur A., Froghi Farrokh V., and Shahidi A. 2002. *Compare two different strategies to assist in locating areas prone to collect rain decision support system (DSS) based on GIS (Case study: Birjand Plain). The eleventh Seminar on Irrigation and reduce evaporation. Kerman. P.8.*

Vanrompai, L. 2003. "*Report on The Technical Evaluation & Impact Assessment of Subsurface Dams (SSDs)"*. TLDP Technical Report. Pp.14.

Zebardast a, 2003, *application of analytical hierarchal (AHP) method in the city and urban planning* architectural journal NR.12 PP.8-16.

Zarghami, m,ehsani, a,2011, *evaluation of different multivariable group decision-making methods*

In the selection of water transfer design of the Oromia lake basin, Iran-water resources to research,3rd. year ,nr.2:1-14.