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Assessment of the potential areas for underground dam construction in Roomeshgan, Lorestan province, Iran

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Abstract

One of the methods for dealing with the problem of water shortage and the decline of groundwater levels in the arid areas is the construction of underground dams. It is difficult to make a decision about suitable locations for the construction of underground dams because of the necessity to consider numerous factors. Some of these criteria are hydrological, geological and geomorphologic characteristics of the area. By applying the GIS and AHP methods, this study attempted to introduce the suitable locations for construction of underground dams in Roomeshgan area in Lorestan Province, Iran. For this purpose, factors such as slope, lithology, land use, alluvium thickness, water quality, and distance from the well, fault and stream and rivers network were used. Using the Analytic Hierarchy Process (AHP) for the possibility of considering various qualitative and quantitative criteria, the process can be one way to select the appropriate location for constructing an underground dam. In this study, after the assessment of the used layers in the Expert Choice software, weight mapping of each layer was prepared. Then, the map of suitable areas for construction of the underground dam was prepared by overlapping the weight mappings of each layer in ArcGIS software. According to the results, 15.87 %, 11.96 %, 35.75 %, 33.23 % and 3.18 % of the region are located in very poor, poor, moderate, suitable and very suitable areas, respectively. After several field surveys of the area with three percent, six locations were selected for underground dam construction. The results show that the factors mentioned above have the most important role in locating the underground dam construction and the chosen method has high accuracy.

Keywords: *Lorestan province, Roomeshgan, Underground Dam, GIS, AHP*

1. Introduction

The strategies for coping with dehydration are summarized in two ways: proper management of water resources; and extraction of new water resources. In most parts of Iran, water resources management is important due to low rainfall and inappropriate time distribution. To this end, in recent years, the national water supply planners have put the dam construction on surface water route on their agenda. The construction of various large and small dams besides considerable advantages in the control and management of surface waters and multi-purpose use to provide water resources and hydropower has widely changed the applications and has left environmental impacts. In recent years, there has been an effort to use nature-friendly technologies in the control and management of water resources, an example of which is the construction of underground dams in different regions (Onder and Yilmaz 2005). The advantages of constructing underground dams are preventing water loss due to less evaporation and transpiration especially in hot and dry regions, preventing water pollution from natural and human pollutants, non-damage to soil resources and lack of land use change due to its underground nature, and reinforcement of groundwater aquifers and using water resources based on the temporal needs.

The advantages mentioned above necessitate extensive studies to select suitable areas for underground dams, especially in low water areas. Underground dams are structures that block the flow of groundwater and cause the formation of water resources under the ground (Eisavi et al. 2012). These dams can play a significant role in maintaining and optimal utilization of groundwater resources due to variety, mechanism, and performance (Kheirkhah Zarkesh et al. 2008).
The use of underground dams in the world, with a simpler structure, smaller size and different examples from today, dates back to the ancient civilizations (Hansson and Nilsson 1988). The world's first underground dam, which built the foundations for today's technology of underground dams, was launched in Pacoimaquic, California between 1887 and 1890, with a length of 200 meters, a maximum height of 17 meters and a thickness of 0.6-meter building wall (Nilsson 1988). In recent years, several methods have been introduced for locating underground dam construction. In this regard, the use of GIS and AHP model can be very effective (Dai 2016). So far, there have been studies in the field in Iran and the rest of the world including the following studies. Foster and Tuinhof (2004) in the assessment of underground dams constructed in Brazil showed that the factors including volume of the reservoir, the depth of bedrock, soil permeability of the reservoir and reservoir soil quality

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have an important role in the success of underground dams. Salami (2006) conducted a study in order to select suitable sites for construction of underground dams after initial assessments and determining suitable criteria. Based on the AHP method, impact factors were prioritized where gradients and geological factors were considered as the most important factors. Furzieri et al. (2008) identified the location of small surface and underground dams in the Kidal region in Mali. They provided a general methodology for evaluating suitable sites for the construction of small dams. Chezgi et al. (2011) introduced 27 points as suitable areas for underground dam construction after the initial assessment and the determination of appropriate criteria for the underground dam in West Tehran. Kordi et al. (2016) located the suitable sites for the underground dam in Mehran, Ilam province in Iran using data layers of the fault, slope, geology, geomorphology, rainfall, temperature and land use in the area. Based on the results of this study, 14 sites were selected for the construction of an underground dam.

This study aimed to locate suitable sites for construction of underground dams to provide drinking and agriculture water in the Roomeshgan area in Lorestan province, Iran. The lack of distribution of rainfall regarding time and location and the absence of a permanent river to cope with the need for this semi-arid plain indicates the necessity of this study.

2. General Information of the Area

Roomeshgan area is located 50 kilometres from the Kuhdasht city and 20 kilometres from Poldokhtar city in the South West of Lorestan province (Fig 1). The city has a temperate and semi-dry climate with a maximum temperature of 40°C in summer and the minimum temperature of 7 degrees below zero in winter with an average annual rainfall of 395 mm. The length of the area is about 24 km and the average width is 6 km.

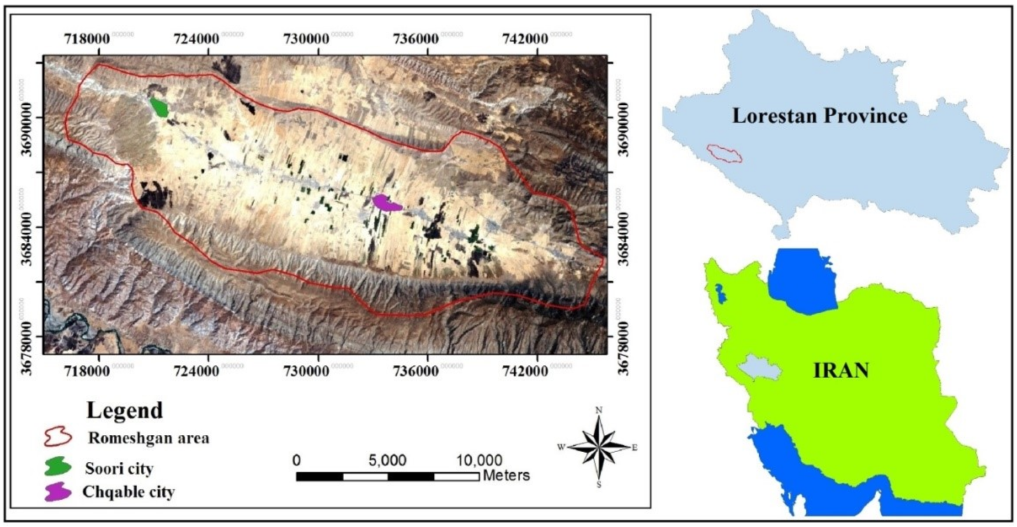

Fig 1. The geographical location of Roomeshgan area.

3. Materials and Methods

3.1. Preparing the criteria

Underground dams are an ingenious method for storing water during wet periods for dispersal during dry times. Essentially, they are similar to above ground dams except that their reservoirs are full of sand to prevent evaporative loss. Water is stored in the porosity of the sand and extracted when needed during dry periods (Telmer and Best 2004; Taleghania and Talabakhshib 2013). Constructing dam is a possible solution for remitting the scarcity of irrigation water resource in Roomeshgan. Considering the complexity of dam site selection, Analytic Hierarchy Process (AHP) was chosen in a combination of Geographic Information System (GIS) as the method of Multi-Criteria Decision Making on selecting dam site (Jamali et al. 2013). Slope, streams and rivers, lithology, land use, soil thickness layer, groundwater quality, distance from well, and faults were considered as criteria in the study, as described below each of those indices.

Slope: To prepare the slope map, the Digital Elevation Model (DEM,) was used which was prepared using the linear alignment of the topographic map of the area (1:50000 scale) in the Arc Map software environment.

Stream and rivers (Waterways): To prepare the boundary map of the distance from stream and rivers network was determined based on the topographic map and then the map was digitized using the Arc Map software.

Lithology: The lithology map of the land surface area was prepared using the geological map of 1:100000 regions, Enhanced Thematic Mapper Plus (ETM+) band images 531 and field studies.

Land use: The land use map of the region was derived using ETM+ sensor satellite data and the interpretation

of the NDVI index and it was completed using field operations.
Alluvial thickness: The map of alluvial thickness was prepared by interpolation between the thicknesses obtained from 31 geoelectrical soundings in the region.
Groundwater quality: The water quality map of the area is prepared using the ArcMap software and an interpolation of the results of analyzing the waters of 21 proper dispersed wells in the region. The laboratory results of water samples of wells were obtained from the Lorestan Regional Water Authority.
Wells: To prepare this layer, first the position of the wells in the area was recorded and then digitized using ArcMap software.
Faults: To provide the layer of faults in the area, geological maps and applying a directed filter on the band of 7 ETM+ sensors in the directions North-South, North East- South West, East-West, and North West-South East was used.

3.2. Analytic Hierarchy Process

In this study, AHP was used to prioritize and to weight the factors affecting the discovery of potentials of an underground dam construction site in the Roomeshgan area. The analytic hierarchy process is one of the most comprehensive models designed for multi-criteria decision making since these techniques provide the possibility of formulating the problem in a hierarchical manner, as well as the possibility of considering different quantitative and qualitative criteria in solving problems. This process allows different options in deciding and provides sensitivity analysis on the criteria and sub-criteria (Janardhana et al. 2006; Azizi et al. 2011). In the analytic hierarchy process, the method applied is first to use oral judgments (expert opinion) based on paired comparisons to determine the priority of different factors and to convert them into quantitative amounts so that the decision maker considers the priority of one factor over the other as in Table (1) and then converts these judgments to qualitative values from 1 to 9. The results of these comparisons are then entered into Expert Choice software to measure the conflicting index. If the calculated index is less than 1.0, the results are acceptable and otherwise, weighting shall be reconsidered.

Table1. Classification of the priority of values of weights based on expert judgment (Saaty 1990).

Classification of class preferences	The numerical value of weights
Quite important or quite desirable	9
Very strong importance	7
Strong importance or utility	5
Somewhat more desirable or somewhat more important	3
Equal importance or desirability	1
Priority between intervals	2, 4, 6 and 8

4. Findings and Discussion

The First step in this research was data collection. For this purpose, maps of a slope, geology, stream and rivers, land use and regional fault were developed. The findings are as follows from 1 to 8:

1. The study of slope classes shows that the gradient of 0-5% is the most suitable class for underground dam construction (Kordi et al. 2016). Assuming that the surface gradient follows partly the bed slope, this could be a reason for not forming a suitable groundwater reservoir in areas with a high slope.
2. In locating underground dams, the amount of runoff is one of the important Factors that have a direct relation with the category of streams. The higher the number of watercourses, the more runoff and more suitable for underground dams. Due to the amount of water required for the reservoir of the dam, sections with higher densities of the drainage network are more suitable, indicating the 3rd-to-high drainage network (Strahler 1952).
3. One of the most important factors in locating underground dams is the study of the geological status of the area. The existence of impervious bedrock, especially in the area of underground dams, as well as types of geological formations and their impact on groundwater quality are important factors to consider (Laa et al. 2005). Investigating the lithology classes indicates that the quaternary sediments (a mixture of sand, gravel, and clay) are the most suitable class for underground dam construction due to more permeability, as well as less impact on reducing the quality of water supplies (Eisavi et al. 2012).
4. The assessment of fault density shows that due to fractures created in areas with a higher density of faults that can be good passages to drain the water and lead it to inaccessible areas, the class with greater density, is the weakest area for the construction of an underground dam (Arjmandzadeh et al. 2017). Therefore, the construction of underground dams on the faults is not suitable due to the possibility of escape of water and increased the cost of preventing leakage (Danaie et al. 2011).
5. Land use: Underground dams do not require surface storage and do not result in land use and ecosystem changes. Since they do not occupy the land surface and do not limit the extent of areas covered by the dam, the construction of these dams in areas with different land use is possible (Pirmoradi et al. 2010). Due to the rising groundwater level behind the dam, many plants can be planted without irrigation at the site of underground dams. The importance of this point is clearly seen in agricultural areas. As the groundwater level rises, the soil moisture of the region greatly increases, which has a significant role in improving irrigation and agricultural conditions. In each case, in order to protect the cleanliness of stored water underground, it should be noted that the land in the area should be used in such a

way that no pollution spreads to the groundwater (José et al. 2016).

6. Always the thickness of the alluvium is equal to the depth of the bedrock. Geologically, to determine the potential areas of underground dams, the average thickness of the alluvial layers and slope with the same direction of the groundwater flow is considered as suitable conditions. It should be noted that the thickness of fewer than 10 meters is considered as an inappropriate condition due to the decrease in the volume of the reservoir and the thickness of alluvium more than 40 meters due to the increase of the operating costs of the dam.

7- Groundwater quality: Underground water quality is one of the most important factors influencing the selection of subterranean dam sites, especially in dams that are used to provide drinking water. In order to determine the quality of groundwater in the Roomeshgan plain, 21 wells have been selected with suitable dispersion in the plain and have been sampled (Table 2). In this investigation, the suitability of groundwater for drinking agricultural uses was measured using Schoeller (1962) and Wilcox (1955) criteria. (Fig 2). The comparison of the quality parameters with the Schoeller table shows that all parameters of the central section are in the good range and the other parts are in "good to acceptable" range (Fig 3, Table 3).

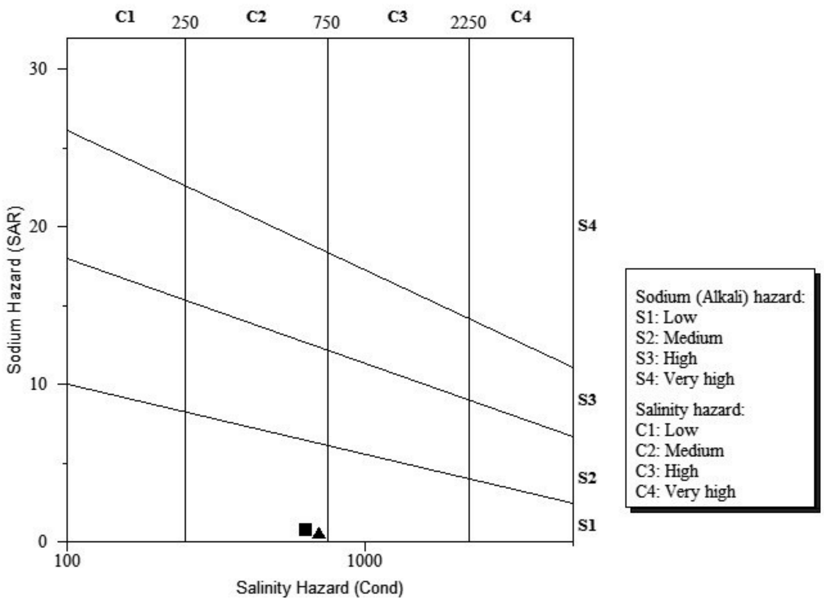

Fig 2. The quality position of the Roomeshgan plain water on the Wilcox chart.

Table 2. The mean values of physicochemical parameters of groundwater in Roomeshgan Aquifer (mg/l).

Regions	pH	Electrical Conductivity (EC) (µs/cm)	Sodium Adsorption Ratio (SAR)	Total hardness (TH)	Total dissolved solids (TDS)	SO_4	Na	Cl
The central part of the region (Average of 6 samples)	7.47	680	1.16	245	474	103	95	85
Other parts of the region (Average of 21 samples)	7.59	731	0.722	275	535	137	55	75

Table 3. Drinking Water quality classification based on Schoeller (1962) (values in mg/L).

Water quality	TDS	TH	Na	Cl	SO_4
Good	500	250	115	175	145
acceptable	500-1000	250-500	115-230	175-350	145-280
Inappropriate	1000-2000	500-1000	230-460	350-700	280-580
Bad	2000-4000	1000-2000	460-920	700-1400	580-1150
Acceptable in emergencies	4000-8000	2000-4000	920-1840	1400-2800	1150-2240
Non-drinkable	>8000	>4000	>1840	>2800	>2240

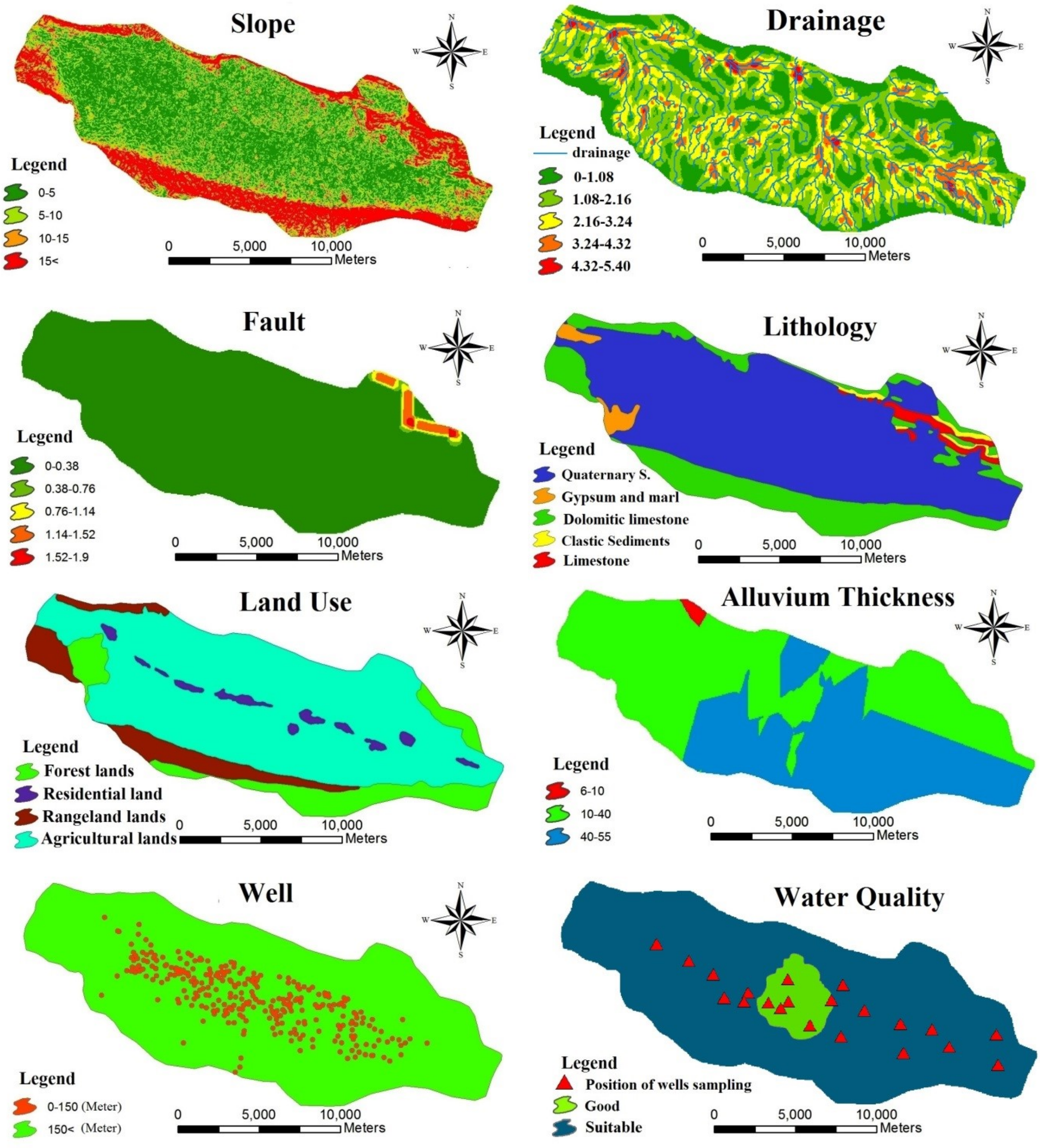

Fig 3. Effective factors maps of the Roomeshgan area.

The Wilcox chart is defined based on two electrical conductivity (EC) and a sodium absorption ratio (SAR). By plotting the values (Table 2) on the Wilcox chart (Fig 2), the results indicate that the Groundwater samples are in the C2S1 class, which, according to Table (4), have a good quality for irrigation.

8. Wells: Wells is one of the water resources in the region, and so far any reason, damage to these valuable water resources, will be accompanied by severe local challenges.

The main purpose of underground dam construction is to help improve the status of the existing water resources and to optimize the use of subsurface flows in the region. Assuming that the creation of a new water source should not lead to damage of the old water resources, therefore, in order to prevent the destruction of wells in the area or the sharp decrease in their discharge, it is necessary to consider at least a distance of 150 meters around them (Rangzan et al. 2013).

In order to weight and prioritize the factors used in locating the underground dam construction, the expert judgment was used. Therefore, factors and sub-criteria were compared two by two and the results were transmitted to the Expert Choice software in the form of a matrix (Tables 5 and 6) and weight of each factors and their sub-criteria were computed (Table 7). The Expert Choice is powerful software that is designed to analyze multi-criteria decision-making issues using the analytic hierarchy process technique and is used to solve multi-criteria decision-making problems, prioritizing goals and weighting. The software is also able to predict the correctness or inaccuracy of the paired comparisons by calculating the incompatibility coefficient. In this research, the incompatibility coefficient of the comparison was calculated as 0.03, which indicates that the comparisons were done correctly.

Finally, after weighing the factors and their classes to prepare the final map for locating the dam, the Raster calculator command in the Arc GIS Desktop software was used and all layers (based on the weights obtained using the Expert Choice software) were added to each other which is ultimately the output of location map of underground dams in Roomeshgan area. Based on the locating, 15.87 %, 11.96 %, 35.75 %, 33.23 % and 3.18 % of the area was in very poor, poor, moderate, suitable, and very suitable zones, respectively. Based on the set of effective factors in locating the underground dam and the map, 9 appropriate sites were identified. By the field visits, 3 sites were removed and six other sites were selected as suitable points for a potential underground dam in the region (Figs 4, 5 and 6, Table 8). Geophysical studies can be used to choose the most suitable point from the six sites. Also, by studying the data obtained from field survey and by plotting suitable sites for the construction of an underground dam on individual maps of the factors, the results showed that the chosen method has high accuracy.

Table 4. Quality of the water resources according to Wilcox classification.

Water Classes	Water Quality	Agricultural Use
C1S1	Drinking Water	Completely harmless
C1S2-C2S2-C2S1	Slightly salty	Almost appropriate
C1S3-C2S3-C3S1-C3S2-C3S3	Salty	Use when necessary
C1S4-C2S4-C3S4-C4S4-C4S3	Too Salty	Harmful to agriculture

Table 5. Comparison matrix of factors used locating underground dams in Roomeshgan area.

	Stream and rivers	Lithology	Slope	Alluvium thickness	Water quality	Land use	Distance from the well	Fault
Stream and rivers	1	2	2	3	3	4	5	6
Lithology		1	2	3	3	4	5	5
Slope			1	2	2	3	4	4
Alluvium Thickness				1	1	2	2	3
Water quality					1	2	2	3
Land use						1	2	2
Distance from the well							1	2
Fault								1

Table 6. Comparative matrix for factor classes used in locating the underground dams in Roomeshgan area.

Factors that affect locating underground dams	**Slope (%)**				
Slope (%)	0-5	5-10	10-15	>15	
0-5	1	5	6	7	
5-10		1	3	5	
10-15			1	3	
> 15				1	
Stream and rivers (km/km^2)	0-1.08	1.08-2.16	2.16-3.24	3.24-4.32	4.32-5.40
0-1.08	1	1/5	1/6	1/8	1/9
1.08-2.16		1	1/4	1.5	1/6
2.16-3.24			1	1/3	1/4
3.24-4.32				1	1/3
4.32-5.40					1
Lithology	Quaternary sediments	Gips and marl	Clastic sediments	Dolomite lime	Lime
Quaternary sediments	1	2	4	5	6
Gypsum and marl		1	3	4	5
Clastic sediments			1	2	3
Dolomitic limestone				1	2
Limestone					1
Alluvium thickness (m)	6-10	10-40	40-55		
6-10	1	1/7	1		
10 40		1	6		
40 55			1		
Water quality	Suitable	Good			
Suitable	1	1/2			
Good		1			
Land use	Agricultural Lands	Rangelands	Forest lands	Residential lands	
Agricultural Lands	1	3	5	6	
Rangelands		1	3	4	
Forest lands			1	3	
Residential land				1	
Distance from the well (m)	0-150	> 150			
0-150	1	1/7			
> 150		1			
Fault density (km/km^2)	0-0.38	0.38-0.76	0.76-1.14	1.14-1.52	1/52-1/9
0-0.38	1	1/4	1/5	1/6	1/7
0.38-0.76		1	1/3	1/4	1/5
0.76-1.14			1	1/3	1/4
1.14-1.52				1	1/3
1.52-1.9					1

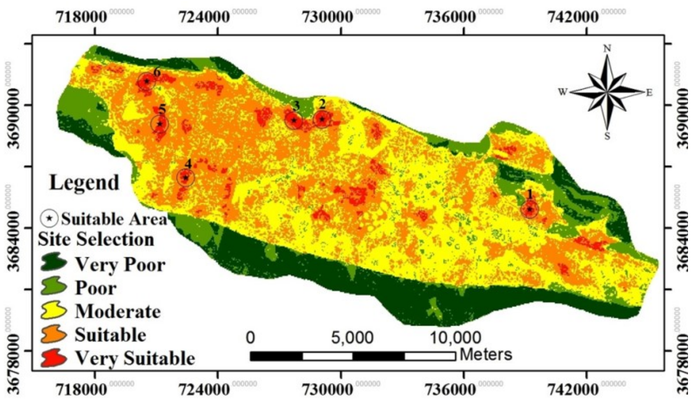

Fig 4. Location map of potential areas for constricting underground dams in Roomeshgan.

Table 7. Weights for the criteria and sub-criteria using the hierarchical method.

Criteria	Weight	Incompatibility coefficient	Sub-criteria	Weight	Incompatibility coefficient	The final weight	Incompatibility coefficient
Slope	0.158	0.02	0-5	0.632	0.09	0.085	0.03
			5-10	0.214		0.029	
			10-15	0.102		0.014	
			>15	0.052		0.007	
Stream and rivers	0.282		0.08- 1	0.029	0.09	0.009	
			0.08-2.16	0.071		0.023	
			2.16-3.24	0.151		0.048	
			3.24-4.32	0.272		0.086	
			4.32-5.04	0.477		0.151	
Lithology	0.232		Quaternary sediments	0.445	0.02	0.125	
			Gips and marl	0.292		0.082	
			Clastic sediments	0.129		0.036	
			Dolomitic limestone	0.081		0.023	
			Lime	0.053		0.015	
Alluvium Thickness	0.092		6-10	0.115	0	0.007	
			10-40	0.764		0.050	
			40-55	0.121		0.008	
Water quality	0.092		Suitable	0.333	0	0.025	
			Good	0.667		0.050	
Land use	0.061		Agricultural Lands	0.559	0.06	0.033	
			Rangeland	0.256		0.015	
			Forest lands	0.123		0.007	
			Residential land	0.063		00.04	
Distance from the well	0.047		0-150	0.167	0	0.005	
			>150	0.833		0.025	
Fault	0.035		0-0.38	0.037	0.08	0.001	
			0.38-0.76	0.082		0.003	
			0.76-1.14	0.146		0.006	
			1.14-1.52	0.264		0.010	
			1.52-1.9	0.471		0.019	

Fig 5. Google earth image of proposed section suitable for the construction of an underground dam on the agricultural area with a length of 800 m and a wall height of 30 m, site 3 of Figure 4.

Fig 6. Proposed place suitable for the construction of an underground dam in the southwest of the region, location 4 of Figure 4, looking towards North-Northeast.

Table 8. Comparison of selected options for locating the underground dam.

Parameters	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Slope (%)	0-5	0-5	0-5	0-5	0-5	0-5
Stream and Rivers (km/km^2)	4.32-5.40	4.32-5.40	3.24-4.32	4.32-5.40	4.32-5.40	3.24-4.32
Lithology	Quaternary Sediment	Quaternary Sediment	Quaternary Sediment	Quaternary Sediment	Quaternary Sediment	Quaternary Sediment
Alluvium Thickness	10-40	10-40	10-40	10-40	10-40	10-40
Water quality	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable
Land use	Agricultural Lands	Agricultural Lands	Agricultural Lands	Agricultural Lands	Agricultural Lands	Agricultural Lands
Distance from the wells (m)	>150	>150	>150	>150	>150	>150
Faults (km/km^2)	0-0.38	0-0.38	0-0.38	0-0.38	0-0.38	0-0.38

5. Conclusion

Roomeshgan in Lorestan province is a semi-arid area that suffers from a lack of water for agriculture and drinking. Therefore, the construction of the underground dam in this area is essential. To locate the most suitable point for underground dam construction in Roomeshgan area, eight factors were studied. In order to prioritize the factors, the analytic hierarchy process was used. The results show that the factors of stream and rivers density, lithology, slope, the thickness of sediments, water quality, land use, wells and density of the fault have the most important role in locating underground dam construction.

Based on the location map, various regional areas of Roomeshgan can be classified in terms of suitability for underground dam construction into five zones: very poor, poor, moderate, suitable and very suitable. The results of several field studies and surveys show that more than three percent of the area is in a very suitable area and six locations were introduced as very suitable locations for underground dam construction that in case of the decision to build the dam, geoelectrical tests and detailed field surveys are essential.

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