Prioritizing suitable locations for underground dam construction in south east of Bushehr Province

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Research Article

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Prioritizing suitable locations for underground dam construction in south east of Bushehr Province

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Abstract
The solutions to deal with the water crisis are summarized into two strategies for managing water resources and extraction of new sources of water. In Iran, due to geographical and climatic conditions, water resources management has a high priority. One of the methods to control and store water in wet periods for using in dry periods is construction of underground dams. The most important problem in the development and creation of underground dams is the complexity of determining the suitable areas for the dams. Developing underground dams can be a viable solution to prevent land use change, the gradual drainage of groundwater and out of reach. The present study was conducted to find the underground dams using Boolean logic and for priority of underground dam sites using MCDM methods include AHP, ANP, VIKOR, TOPSIS and ELECTRE III in four provinces of Bushehr, Tangestan, Dashti, and Jam in southern Iran. The results obtained by Boolean logic showed that the total area of the studied site had about 305 km potential for underground dam construction. In the next step, according to Google Earth images and based on different indices including, axial length, reservoir, lithology, distance from village and roads, 23 potential axes were identified afterward, by extensive field surveys, among these 23 potential axes, 6 locations were identified as suitable locations. In order to prioritize these six areas, the MCDM models were used. Finally, the results of the MCDM models showed that sites have different ranks of 1 to 6 for constructing underground dams. In the end for determined the final rank using Copeland method that result showed Zayer Abbasi site was in the first priority and Faghih Hasenan site is in sixth priority. ANP and AHP method near the Copeland method.

***Keywords**:* Underground dam, ANP model, Copeland method, Boolean logic, Site selection, GIS

Introduction

One of the most important parts of Iran is arid and semi-arid regions. The average rainfall in Iran is less than one-third of the average rainfall in the world (Nayebi et al. 2016). In addition to, shortage of rainfall and its local and time distribution is also very inconvenient (Nayebi et al. 2016; Dortaj et al. 2019). Therefore, due to the extraordinary importance of water in arid and semi-arid regions, it is necessary to provide scientific and innovative solutions for the optimal use of water resources. In addition, groundwater resources are expanding due to increasing population, welfare levels, and increasing technology (Cantalice et al. 2016; Jamali et al. 2018; Lima et al. 2018; Dortaj et al. 2019). The solutions to deal with the water crisis are summarized into two strategies for managing water resources and extraction of new sources of water that in Iran, due to geographical and climatic conditions, improvement of management of water resources is a priority and will have better and faster results (Ngigi 2003; Gomes et al. 2018). So, one of the methods of water control and management, is storage of water in wet periods to use in dry periods. This subject could consider by construction of underground dams. Underground dams are structures that have the ability to block water under the surface, to divert water from adjacent aquifers, and high groundwater level (Telmer and Best 2004; Freitas et al. 2011; Cantalice et al. 2016; Jamali et al. 2018; Lima et al. 2018; Dortaj et al. 2019). These types of dams are usually constructed in the ephemeral riverbeds by a lot of drainages (Telmer and Best 2004; Gomes et al. 2018; Lima et al. 2018). One of the applications of underground dams is to store water on a small scale and increase water volume (Barkhordari 2015; Cantalice et al. 2016). Underground dams can be a viable solution to prevent groundwater loss due to gradual salinization on the way to or from deserts and saltwater lakes and generally out of reach (Ishida et al. 2011; Ansarifar et al. 2017).

The most important problem in the development and creation of underground dams is the determination of suitable areas for dam construction. This problem arises because of many criteria and effective factors including; social, economic, geological, and hydrologic in their proper locations. Determining the suitable location of the underground dams based on traditional methods, it is so complex, time consuming, and costly; so, new methods can be used to design suitable sites for this aim with high precision and savings in time and cost (Jamali et al. 2014; Shirani et al. 2017; Gomes et al. 2018; Talebi et al. 2019). Various studies have been conducted on the construction of the underground dam as follow:

Jamali et al (2013) tried to locate suitable areas for the construction of underground dams using the Geographic Information System (GIS) in the Buddha Cal Region of Sudan. The results showed six areas were identified as suitable locations for constructing underground dams. Jamali et al (2014) used of the Analytical Hierarch Process (AHP) and Factor Interaction Method (FIM) to locate underground dams in northern Pakistan. The results showed that the AHP method has more capability than the FIM in site selection of underground dams. Marchival and Singh (2015) investigated the underground water storage areas in Udaipur, India using Multi-Criteria Decision Making (MCDM) Algorithm and Boolean logic (BL). The results showed that 36.07 square kilometers (10 percent of the total area) and 30.55 square kilometers (9 percent of the total area) of the study area were presented as appropriate areas by the MCDM and BL, respectively. Cantalice et al (2016) examined the hydrology and water quality of the underground dams in the Jacu River Brazil. The results showed that during the dry season, salt concentration increased in the underground dams. The reason for this is excessive irrigation water. In contrast, in the rainy season, the Electrical Conductivity (EC) of irrigation water was reduced to a salinity level of 0.95 dS m-1 (C1). The results also showed that underground dams can increase groundwater level in the region. Gomes et al (2017) determined the suitable areas for the construction of an underground dam in the Minas Jenipapo area in south east Brazil using the results of geophysical experiments. Geoelectric results showed that the layers with low electrical resistance (less than 400 Ω-M) indicates a water-saturated sandy layers in basement. Due to its porosity and high permeability, the layer can store a significant amount of water in the basement and create suitable conditions for the construction of underground dams. Gomes et al (2018) considered construction of underground dams in southeast of Brazil. The results showed that the best areas for the construction of the underground dam is the dry bed of the Boals River, where due to the presence of sandy soil in the bed, underlying streams are active as a result of water penetration during the rainy season and it could be a suitable bed for the construction of underground dams. Yifru et al (2018) investigated the effects of sand-dams on the flow of groundwater. The results showed that groundwater was significantly increased after the construction of sand dams.

A survey of research history shows that the factors influencing in site selection of groundwater dams are different in various regions. Therefore, this study is very necessary considering the economic and social conditions and the issue of water constraints in the region. Also, in most of these investigations, underground dams have been located in traditional ways. Although, in recent years these types of studies have been considered with the help of modern methods. Lafayette et al (2019) experimented and modeled soil evaporation in an underground dam in the semi-arid region of Pernambuco, Brazil. The results showed that the Simple Soil Plant Atmosphere Transfer (SiSPAT) model was quite satisfactory for simulating soil evaporation under different water depth conditions. Baharvand et al (2020) studied the Roomeshgan watershed in Lorestan using multi-criteria MCDM decision making and the Boolean method to determine suitable areas for the construction of an underground dam. The results showed that 15.87%, 11.96, 35.75, 33.23% and 3.18% of the region were located in very poor, poor, medium, suitable and very suitable areas, respectively.

Bushehr Province is located in arid and semi-arid region of Iran via irregular distribution of rainfall in time and place, the limitations of surface and underground water resources and Quaternary sensible formations are suitable for underground water storage. Therefore, the construction of underground dams is one of the effective strategies for storing water and coping with drought in Bushehr Province, Iran. The purpose of this research is to locate an underground dam in southeast of Bushehr Province. The results show that most researchers have used simple decision - making methods to determine the location of underground dams that has a hierarchical structure and in principle, criteria and sub-criteria are independently measured. In the event that in nature, the criteria and sub-criteria are in relation to each other and affect each other. For example, the sub - criteria of permeability, which is one of the most important parameters in the location of the underground dam it is influenced by the geology, slope, vegetation, and other factors that flow in nature that is not considered in simple ways. In this study, AHP, Analytical Network Process (ANP), Elimination ET Choice in Translating to Reality III (ELECTRE III), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Vlse Kriterijumsk Optimizacija Kompromisno Resenje (VIKOR) methods were used for ranking. The results were then combined using the Copeland method to provide the best possible location for more accurate studies.

Materials and methods

Study area

The present study was done in part of Bushehr Province (Figure 1). This province lies in southern Iran, and covers an area of about 25,359 square kilometers in a narrow strip between the Gulf and the foothills of the Zagros Mountain. Geographically, the Bushehr Province is between the latitudes of 27° 14\` to 30°16\` north and the longitudes of 50°16\` to 52°58\` east. The Bushehr Province has nine cities that four cities studied in the current research including Bushehr, Tangestan, Dashti, and Jam which their area is 1442, 1927, 4500, and 1952 km^2, respectively (Mashayekh et al. 2012). The climate in Bushehr province is warm and dry but with high relative humidity especially in summer. The average annual temperature and precipitation in the province are 24 ° C and 220 mm, respectively (Kanein 2008). The rains occur in the autumn and winter seasons (Kanein 2008).

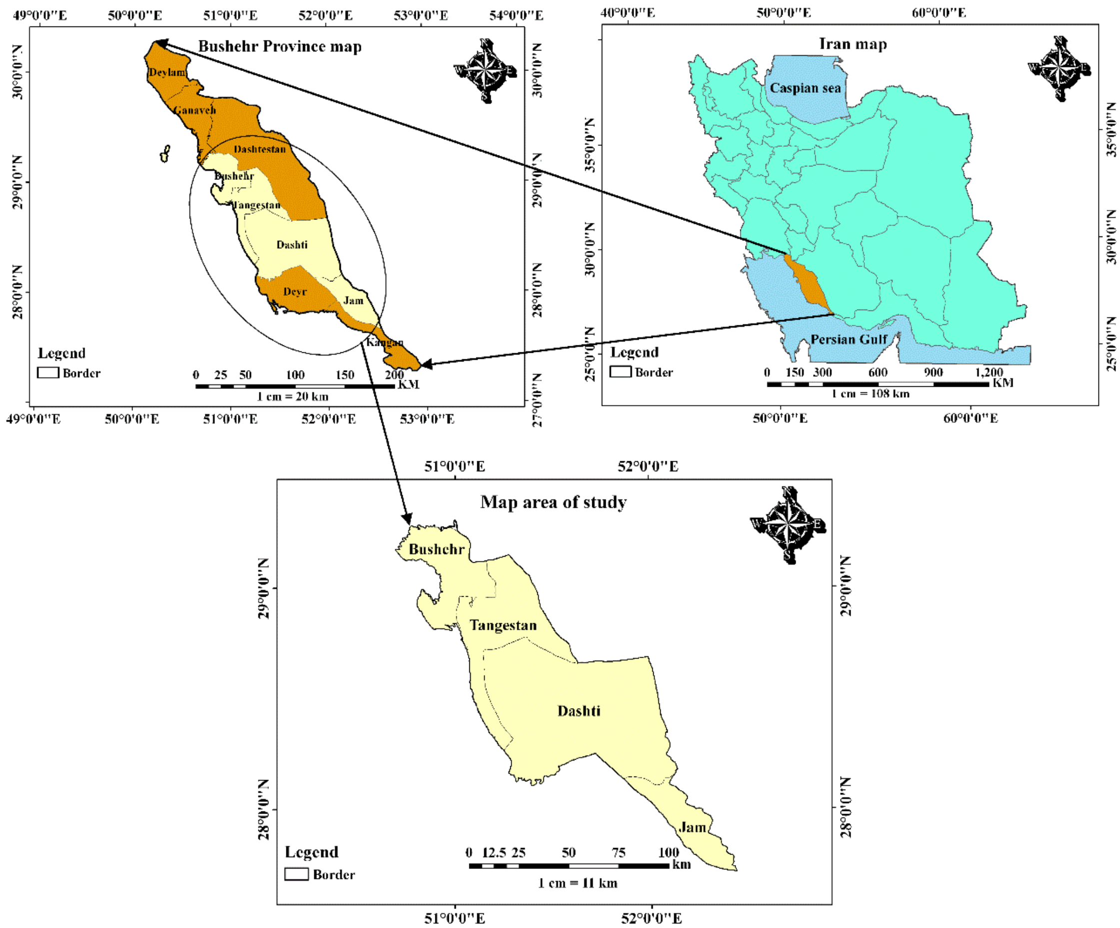

Fig 1. The map of the studied area

Data used

Influential factors on the site selection of underground dams are including meteorological and hydrometric data were obtained from meteorological organizations and wells, springs, and Qanats with a scale of 1: 100,000 from Bushehr Provincial Water Authority. Faults, land use, and geology data with a scale of 1: 100,000 were obtained from the General Department of Natural Resources and Watershed Management of Bushehr Province and a Digital Elevation Model (DEM) map of 10m was obtained from the Iranian Surveying Organization (ISO). Data on water quantity and quality and water demand (potable, agricultural and industrial) from regional water and industry, mining and commerce, rural and urban areas and roads with a scale of 1: 100,000 from Bushehr Province Road and Urban Development Organization Bushehr received. These data were then prepared in GIS environment. The process of doing this is shown in figure 2.

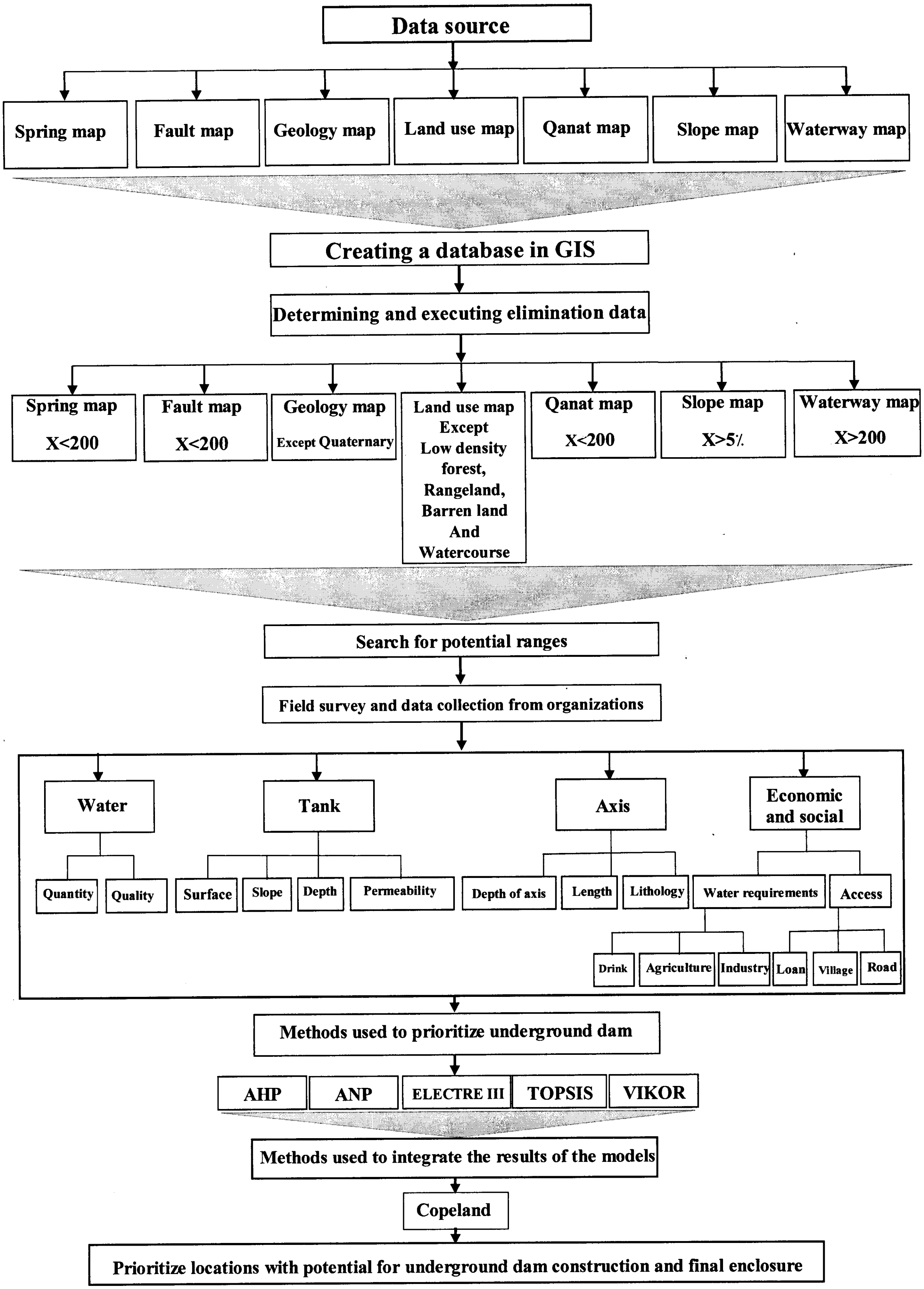

Fig 2. Flowchart of identification of appropriate areas for locating underground dam construction

Methodology

For finding and suggesting suitable areas of construction of underground dams, it is important to identify effective factors. For this aim, different factors (including, waterways, slopes, Qanats and springs, land use, geology, and faults were selected. In general, and according to literature review (Jamali et al. 2018; Khorrami and Rezaei 2018; Kharazi et al. 2019), a distance of more than 200 meters from Qanats, springs, and faults, also slopes of less than 5 percent, low-density forest lands, rangeland, barren land and watercourse, distances of less than 200 meters from the waterway, and quaternary formations were separated as proper areas at first step. The bed slope should be less than 5%, since these areas affected by low and medium runoff, which can be suitable areas for the construction of an underground dams (Barkhordari 2015). The geology of upstream dams must have high permeability so that a reservoir of optimal volume could be expected. The underground dam should be constructed at a distance of more than 200 meters from the fault because it is dangerous for the structure, and it may also cause water to escape from the reservoir. The underground dam should be more than 200 meters away from the springs and Qanats, because as they will affect their discharge. (Barkhordari 2015; Jamali et al. 2018; Rohina et al. 2019). It should be noted that if the underground dam is constructed below the aqueduct and springs, it will increase the discharge and water level and if it is constructed above the aqueduct and the spring, it will reduce the discharge of the aqueduct and the spring. (Chezgi et al. 2016b). In the first step, BL method was used. BL is derived from the name of the famous mathematician, which has been used in many researches because of its simplicity of logic and calculations. In this model, weighing is based on two modes: zero (inappropriate) and one (appropriate). To generate the final map in this model, there are different operators AND, OR, NOT (Jamali et al. 2014; Farokhzadeh et al. 2015; Chezgi et al. 2016a; Rohina et al. 2019). Regarding the purpose of this study, AND operator was used.

After integrating information layers using BL, zero-numerical value pixels correspond to inappropriate zones and one-numerical value pixels correspond to regions with the potential to construct an underground dam (Jamali et al. 2013; Farokhzadeh et al. 2015). In the second stage, after identifying the suitable areas according to BL, the suitable axes in each area should be specified. Firstly, in the straits of each area, several axes were identified. The most suitable axes are those which, in addition to the short length axis of the dam, have a large surface expansion of the reservoir in the upstream axis (Nilsson 1988; Kharazi et al. 2019; Talebi et al. 2019). Finally, suitable axes were identified. Then, in order to confirm the suitable axes, the field visit is done based on the criteria of water (quantity and quality), reservoir (slope, permeability, surface, and depth), axis (altitude, length, and lithology), and socio economic factors (distance from village, distance from road, distance from resources of the loan, water needs including drinking, agricultural land, industry, and impact on Qanats). It should be noted that the validation of the axes was done using the studies carried out in this field as well as the views of the relevant experts and professors (Jamali et al. 2018; Dortaj et al. 2019; Talebi et al. 2019). Considering that the subterranean dams did not have any effect on the Qanats, the impact factor on the Qanats was eliminated from the sub-criteria and 11 sub-criteria were used to prioritize the appropriate locations. A most crucial step in subsurface dam's site selection is criteria weighting (Dortaj et al. 2019). After extracting all the criteria and sub-criteria required in this study and preparing expert opinion forms, degree of incompatibility of the mentioned experts evaluated (Farokhzadeh et al. 2015; Dortaj et al. 2019). In this study, 6 experts form academic staffs and 5 specialist experts from research institutes collaborated on this research. Finally, the data entered to the AHP model and were ranked according to expert opinions. Then, using the Super Desion software, the pair-wise comparisons was done based on Table 1 and the weight of the criteria was obtained (Saaty 1980; Tabari et al. 2011). It is important to control incompatibility rate of decision maker's judgments based on mathematical relations in the AHP model, it done using Super Decision software. According to different sources (Tabari et al. 2011), the inconsistency rate should be less than 0.1. Since Saaty (1980) has proposed the AHP method for solving problems that have a mode of independence between options and criteria (Saaty 1980; Dortaj et al. 2019; Rohina et al. 2019), due to the dependence of the factors affecting the construction of an underground dam, the ANP model which considers all external and internal dependencies, AHP, ELECTRE III, TOPOSIS and VIKOR, were used (Asghari Saraskanroud et al. 2016; Talebi et al. 2019). The weight of the AHP criteria in model was introduced into the ELECTRE III, TOPOSIS, VIKOR and ANP (the internal connection was made in the ANP model), ELECTRE III, TOPOSIS and VIKOR model. Because the models we used for ranking were more than one and did not provide the same rankings for all options, we used the integration of the results from the models, the Copeland method, which is a modified Borda method. Finally, prioritization of suitable and potential locations obtained from the field visit for the construction of an underground dam in the study area.

AHP:

Step 1: Creating a hierarchical chart

The first step in the hierarchical analysis process is to create a hierarchical diagram of the problem, in which the goal, criteria (if there are sub-criteria), and options are usually displayed, respectively.

Step 2: Form a pairwise comparison matrix

At this stage, the elements of each level are compared in pairs at a higher level than other related elements, and even comparisons are formed. Allocation of numerical points related to pairwise comparison, importance of two options or two indicators is done based on Table 1.

Table 1. A scale for performing pair-wise comparisons (Saaty 1980)

Preferences	Numerical value
Absolutely more important	9
Strongly more important	7
More important	5
Slightly more important	3
Equally important	1
Absolutely more important	2,4,6, and 8

A pairwise comparison matrix is displayed below:

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \dots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \qquad \text{Relation (1)}$$

Where a_{ij} is the preference of element i over element j. In comparing a pair of criteria to each other, the following relationship is established by inverse condition:

$$a_{ij} = \frac{1}{a_{ji}} \qquad \text{Relation (2)}$$

Step 3: Calculate the weight of the elements

The weight of each option is the sum of the product of the weight of each criterion in the score of the desired option, which is obtained from the following equation:

$$A = \sum_{j=1}^{n} a_{ij} \,.\, W_j \qquad i = 1, 2, \dots, m \qquad \text{Relation (3)}$$

Where aij indicates the relative importance of option i for the criterion cj and wj indicates the significance of the criterion cj. It is also necessary that the values of the options and the weight of the indicators be normalized using the relations.

$$\sum_{i=1}^{m} a_{ij} = 1 \qquad j = 1, 2, \dots, n \qquad \text{Relation (4)}$$

$$\sum_{j=1}^{n} W_j = 1 \qquad \text{Relation (5)}$$

Step 4: Calculate the incompatibility rate

One of the advantages of the hierarchical analysis process is the control of decision consistency, in other words, in the process of hierarchical analysis, the consistency of the decision can always be calculated and judged as good or bad or accepted or rejected. Therefore, a measure must be found that shows the degree of inconsistency of the judgment. The hourly mechanism (Saaty 1980) for examining inconsistencies in judgments is the calculation of a coefficient called the inconsistency coefficient (I.R), which is obtained by dividing the inconsistency index (I.I) by the random incompatibility index (R.I.I). If this coefficient is less than or equal to 0.1, consistency in the judgments is acceptable, otherwise the judgments should be reconsidered (Jamali et al. 2014; Chezgi et al. 2016a; Ataei 2018; Dortaj et al. 2019)

$$I.R = \frac{I.I}{R.I.I} \qquad \text{Relation (6)}$$

The method of the ANP was first introduced by Saaty (1980). The network analysis process is a general case of the hierarchical analysis process model and its broad form. Therefore, all its positive features, including simplicity, application of quantitative and qualitative criteria simultaneously and take into account its flexibility. This model replaces the network structure with the hierarchical structure, which suggests that all elements in a network can, in any way, be related to each other. For example, it can be said that not only the importance of the criteria determines the importance of the options in the hierarchy, rather, the importance of options may also influence the importance of the criteria (Chezgi et al. 2016a; Eshghizadeh 2017; Talebi et al. 2019).

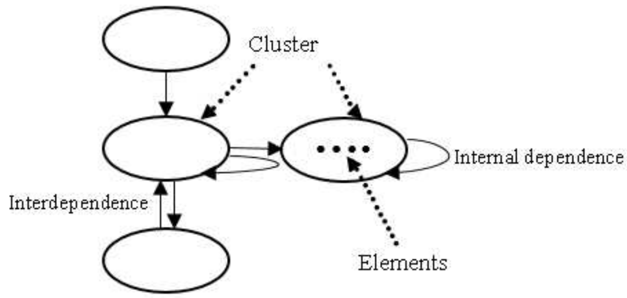

Fig 3. Network analysis method (Ataei 2018)

Steps of the network analysis process method

Figure 3 shows the decision view process in the network analysis process method. According to this process, the steps of this algorithm are as follows:

Step1: Model building and problem configuration

In the first stage, the problem must be clearly defined and then its components are divided into a logical and orderly structure, in the form of a network with logical connections (Figure 3). At this stage, the criteria that influence the final decision are identified. These criteria are set by senior managers and key decision makers or expert staff who have sufficient knowledge of the entire system. Once the network elements are identified, they are connected to each other, which is based on the type of connection to their internal elements. The relationship of the components in the network indicates the influence of the elements on each other. This connection is indicated by an arc that is drawn from the source category to the target category, and if the target category is that category, the arc will be a reverse arc.

Step 2: Formation of pairwise comparison matrices and calculation of weight vectors

Similar to the hierarchical analysis method, the pairwise comparison matrices of the effect of criteria and sub-criteria are formed by considering the higher levels of network and internal communication, so that the weight of the elements can be obtained with their help. These weights vary from 1 (equal importance) to 9 (absolute importance) by hourly definition.

Step 3: Form a Super matrix

A super matrix is a matrix of relationships between network components that is obtained from the priority vectors of these relationships.

More generally, the super matrix will be as follows, in which the weights at different levels of the model are given in the rows of the matrix:

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \cdots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \qquad \text{Relation (7)}$$

Each W_{ij} of this matrix represents the weight vector of the pairwise comparison performed at the relevant level. Since it is possible for factors to be influenced by each other on the same level, the sum of the weights in the columns will not be equal to one.

Step 4: Calculate the permanent distribution of the weighted super matrix

This is similar to the Markov chain process by enabling the weighted supermatrix to a large number, namely:

$$\lim_{k\to\infty} W^k \qquad \text{Relation (8)}$$

If the static distribution matrix converges to a final matrix, this final matrix is used as a weight measurement criterion for the options. If this matrix does not converge to a vector, all matrices to which convergence is done periodically will be intercepted:

$$\lim_{k\to\infty} \left(\frac{1}{n}\right) \sum W_i^k \qquad \text{Relation (9)}$$

Step 5: Normalize the weights obtained by considering each cluster

Step 6: Select the top option

In this step, the weights obtained in the previous step will be used to identify the superior option (Chezgi et al. 2016a; Eshghizadeh 2017; Ataei 2018; Talebi et al. 2019).

The VIKOR method was invented in 1988 by Opricovic and Tzeng. VIKOR's approach is to solve a decision problem with disproportionate criteria. In fact, it uses agreed-upon solutions to problems that are close to the ideal solution and have the maximum group utility, at least unfortunate for decision makers. That has attracted the attention of many researchers in recent years (Opricovic and Tzeng 2004, 2007; Ameri et al. 2018).

If there are n criteria and m options in a multi-criteria decision problem, in order to select the best option using this method, the steps of the method are as follows:

Step 1: Formation of decision matrix

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ldots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \qquad \text{Relation (10)}$$

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

Step 2: Scaling the decision matrix

$$F = \begin{bmatrix} f_{11} & f_{in} \\ f_{m1} & f_{mn} \end{bmatrix} \qquad \text{Relation (11)}$$

In this matrix:

$$f_{ij} = (x_{ij}) / (\sqrt{\textstyle\sum_i^m x_{ij}^2})$$

Relation (12)

Step 3: Determining the weight vector of criteria

At this stage, according to the coefficient of importance of different criteria in decision making, vector is defined as follows:

$$W = [w_1, w_2, \ldots, w_n] \quad \text{Relation (13)}$$

Step 4: At this stage, according to the coefficient of importance of different criteria in decision making, vector is defined as follows

The best values of (f_j^*) for the positive and negative criteria are calculated from the following equations, respectively:

$$f_j^* = \underset{i}{\mathrm{Max}}\, f_{ij} \quad \text{Relation (14)}$$

$$f_j^* = \underset{i}{\mathrm{Min}}\, f_{ij} \quad \text{Relation (15)}$$

The worst values of (f_j^-) for the positive and negative criteria are calculated from the following equations, respectively:

$$f_j^- = \underset{i}{\mathrm{Max}}\, f_{ij} \quad \text{Relation (16)}$$

$$f_j^- = \underset{i}{\mathrm{Min}}\, f_{ij} \quad \text{Relation (17)}$$

In this case, f_j^* is the best value of the criterion j of all the options and f_j^- is the worst value of the criterion j of all the options.

Step 5: Calculate the amount of usefulness (S) and the amount of regret (R)

$$S_i = \sum_{j=1}^{n} w_j \frac{f_j^* - f_{ij}}{f_j^* - f_j^-} \quad \text{Relation (18)}$$

$$R_i = Max\left\{w_j \frac{f_j^* - f_{ij}}{f_j^* - f_j^-}\right\} \quad \text{Relation (19)}$$

Where w_j is the desired weight value for criterion j.

In the agreement planning method, if the parameter P is equal to one, the same value of S_i is obtained:

$$L(A_i) = \left(\sum_{j=1}^{n} w_j \frac{f_j^* - f_{ij}}{f_j^* - f_j^-}\right) = S_i \quad \text{Relation (20)}$$

$$L_\infty(A_i) = Max\left[w_j\left(\frac{f_j^* - f_{ij}}{f_j^* - f_j^-}\right)\right] = R_i \quad \text{Relation (21)}$$

Step 6: Calculation of VIKOR index (Q value)

The value of Q is calculated according to the following equation:

$$Q_i = v \left[\frac{S_i - S^-}{S^* - S^-}\right] + (1 - v)\left[\frac{R_i - R^-}{R^* - R^-}\right] \qquad \text{Relation (22)}$$

$$S^- = Min\ S_i \qquad S^* = Max\ S_i \qquad R^- = Min\ R_i \qquad R^* = Max\ R_i \qquad \text{Relation (23)}$$

In these relationships:

$((S_i - S^-) / (S^* - S^-))$ represents the distance rate from the ideal solution, and $((R_i - R^-) / (R^* - R^-))$ represents the distance rate from the counter-ideal solution, and the parameter v is selected according to the degree of agreement of the decision-making group. In case of high agreement, its value will be more than 0.5, in case of agreement with the majority of votes, its value will be equal to 0.5 and in case of low agreement, and its value will be less than 0.5. The value of Q is a function of S_i and R_i, which themselves are the values of the distance from the ideal solution for P = 1 and P = ∞, respectively, in agreement programming.

Step 7: Sort options by R, S and Q

At this stage, according to the values of R, S and Q, the options are arranged in three groups, from smaller to larger. Finally, an option is selected as the top option that is recognized as the top option in all three groups. It should be noted that in group Q, an option is selected as the top option that can meet the following two conditions:

Condition 1: If the options A_1 and A_2 represent the first and second top options in the group and n, respectively, the number of options, the following relationship is established:

$$Q\ (A_2) - Q(A_1) \geq \frac{1}{n-1} \qquad \text{Relation (24)}$$

Condition 2: Option A_1 must be recognized as the top rank in at least one of the groups R and S.

When the first condition is not met, the following set of options are selected as the top options:

Top options = $A_1, A_2, \ldots, A_m$

The maximum value of m is calculated according to the following equation.

$$Q\ (A_m) - Q(A_1) < \frac{1}{n-1} \qquad \text{Relation (25)}$$

When the second condition is not met, the two options A_1 and A_2 are selected as the top options (Opricovic and Tzeng 2004, 2007; Ataei 2018; Ameri et al. 2018).

The ELECTRE III model was first introduced in 1992 by Yu. The ELECTRE III model is one of the most powerful multi-criteria programming methods that by applying fuzzy conditions and considering different types of communication between options, it is considered the most complete method in the set of ELECTRE methods and at the same time over time. Spends more on solving the problem. The ELECTRE III method is more applicable to prioritization problems. This approach brings many decision makers into the decision-making process, as well as being able to analyze a large number of evaluation criteria (Park et al. 2015; Dortaj et al. 2019, 2020). Steps are summarized as follows:

Step1: Construct decision matrix

In the decision matrix, the specifications of the options are mentioned in terms of criteria. In this matrix, the element corresponding to option a_i and the criterion k are represented by the symbol g_{kai}. Therefore, the decision matrix will be as follows;

Table 2. Decision matrix (Ataei 2018)

Options	C_1	C_2	C_N
a_1	g_{1a1}	g_{2a1}	g_{na1}
a_2	g_{1a2}	g_{2a2}	g_{na2}
a_m	g_{1am}	g_{2am}	g_{nam}

Step2: Define thresholds and assign weights to criteria

In this method, in order to strengthen the ability to identify the best options and also to involve decision makers in the selection process, three new thresholds are used. These thresholds are the Veto threshold (q), preference threshold (p), and indifference threshold (τ). For instance, τ_k, p_k and q_k represent veto, preference and indifference thresholds for criterion k, respectively (Fig.4). The quantities of these thresholds are decided by individual or a team of experts.

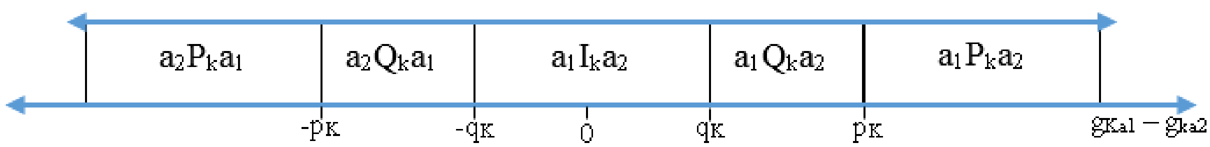

Fig 4. The concept of thresholds in ELECTRE III method (Ataei 2018)

Therefore, the experience and knowledge of the decision maker has a very fundamental role in determining these indicators. As shown in Fig. 4, while comparing two alternatives a_1 and a_2 concerning criterion k, (comparing g_{ka1} and g_{ka2}), five situations are possible:

If $-q_k < g_{ka1} - g_{ka2} < q_k$, then a_1 and a_2 are nearly equal and it is shown by $a_1I_ka_2$. Relation (26)

If $q_k < g_{ka1} - g_{ka2} < p_k$, then a_1 is preferred to a_2 and it is represented by $a_1Q_ka_2$.

If $pk < g_{ka1} - g_{ka2}$, then a_2 is vetoed by a_1 completely and it is presented by $a_1P_ka_2$.

If $-p_k < g_{ka1} - g_{ka2} < -q_k$, then a_2 is preferred to a_1 and it is illustrated by $a_2Q_Ka_1$.

If $g_{ka1} - g_{ka2} < -p_k$, then a_1 is vetoed by completely and it is shown by $a_2P_ka_1$.

One of the important parameters in choosing the right option in this method is the weight or degree of importance of each criterion. The weight of existing criteria is also generally determined by experts and decision makers. The total weight of the criteria is one.

Step3: Form the consent matrix for each criterion

A preferential matrix (c_k) is formed using the decision matrix formed in the first step and the thresholds set in the second step and according to the relationship of the options in terms of each of the criteria. Each element of this matrix is calculated using the following equation:

$$C_k(a_1, a_2) = \begin{cases} (g_{ka1} + p_{ka2} - g_{ka2}) / p_{ka2} - q_{ka2} & \text{if } q_{ka2} < g_{ka2} - g_{ka1} < p_{ka2} \\ 1 & \text{if } g_{ka2} - g_{ka1} \leq q_{ka2} \\ 0 & \text{if } p_{ka2} < g_{ka2} - g_{ka1} \end{cases} \quad \text{Relation (27)}$$

Step4: Formation of the general agreement matrix

A total preference matrix (C) is formed using a method called weight averaging process.

w_k presents the weight of criterion k.

$$C(a_1, a_2) = \left(\left(\sum_{k=1}^{n} w_k C_k(a_1, a_2)\right) / \sum_{k=1}^{n} w_k \right. \quad \text{Relation (28)}$$

Step 5: Form an opposition matrix for each criterion

At this stage, using the decision matrix as well as the set thresholds, the opposition matrices in terms of each of the criteria (D_k) are formed using the following equations:

$$D_K(a_1, a_2) = \begin{cases} (g_{ka1} + p_{ka2} - g_{ka2}) / \tau_{ka2} - p_{ka2} & \text{if } p_{ka2} < g_{ka2} - g_{ka1} < \tau_{ka2} \\ 1 & \text{if } \tau_{ka2} < g_{ka2} - g_{ka1} \\ 0 & \text{if } g_{ka2} - g_{ka1} \leq p_{ka2} \end{cases} \quad \text{Relation (29)}$$

Step 6: Formation of the general opposition matrix:

At this stage, according to the opposition matrices formed for each of the criteria, the total opposition matrix (D) is formed by weighting:

w_k presents the weight of criterion k.

$$D(a_1, b_2) = \left(\left(\sum_{k=1}^{n} w_k D_k(a_1, a_2)\right) / \sum_{k=1}^{n} w_k \right. \quad \text{Relation (30)}$$

Step 7: At this stage, the validity matrix (S) is formed between different options based on the above two matrices. The validity of the validity matrix is comparable using the following mathematical equation:

$$S(a_1, a_2) = \begin{cases} C(a_1, a_2) & \text{if } D_k(a_1, a_2) \leq C(a_1, a_2) \\ C(a_1, a_2) \prod_{\{k_{i:} D_k, (a_1, a_2)\}} (1 - D_K(a_1, a_2)) / (1 - C(a_1, a_2)) & \text{otherwise} \end{cases}$$

Relation (31)

Step 8: Formation of the final comparison matrix

According to the s matrix calculated in step 7, to form the final comparison matrix, indices λ and S (λ) are defined and calculated as follows:

$\lambda = \max(S)$

$S(\lambda) = 0.3 - 0.15\lambda$ Relation (32)

The final disparity matrix (T) is then formed using the following equation:

$$T(a_1, a_2) = \begin{cases} 1 & \text{if } S(a_1, a_2) > \lambda - S(\lambda) \\ 0 & \text{otherwise} \end{cases}$$ Relation (33)

Step 9: Perform the ranking process

After forming the final comparison matrix, in order to prioritize the options under consideration, once the options are sorted from the best to the worst and once from the worst to the best. Finally, by comparing the two trends of increasing and decreasing, the final ranking of the options is obtained (Park et al. 2015; Ataei 2018; Dortaj et al. 2019, 2020).

The TOPSIS model was developed by Hwang and Yoon in 1981 and is one of the best multidisciplinary decision models. In this way, the options are ranked on the basis of similarity to the ideal solution (whichever is the better). So that an option resembles the ideal solution, it will rank higher. This method is based on the notion that the chosen option must have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution (Opricovic and Tzeng 2004, 2007; Ameri et al. 2018).

If there are n criteria and m options in a multi-criteria decision problem, in order to select the best option using the similarity to ideal solution method, the steps of the method are as follows:

Step1: Formation of decision matrix

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \dots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix}$$ Relation (34)

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

Step 2: Scaling the decision matrix

In this step, we try to convert criteria with different dimensions into dimensionless criteria and the R matrix is defined as follows:

$$R = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \dots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{bmatrix}$$ Relation (35)

The following equation is used to scale:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$$ Relation (36)

If the distance between the measured values is not large, the following equations can be used to scale the positive and negative criteria, respectively:

$$r_{ij} = \frac{x_{ij} - min\,(x_{ij})}{max\,(x_{ij}) - min\,(x_{ij})}$$ Relation (37)

$$r_{ij} = \frac{max\,(x_{ij}) - x_{ij}}{max\,(x_{ij}) - min\,(x_{ij})}$$ Relation (38)

Step 3: Determine the weight vector of the criteria

At this stage, according to the importance coefficients of different criteria in decision making, the weight vector of the criteria is defined as follows:

$$W = [\,w_1 \quad w_2 \quad \dots \quad w_3]$$ Relation (39)

The elements of the vector W are the coefficient of importance of the relevant criteria.

Step 4: Determine the unmeasured weighted decision matrix

Weighted unmeasured decision matrix is obtained by multiplying the unmeasured decision matrix by the weight vector of the criteria:

$$v_{ij} = w_j\, r_{ij} \qquad j = 1, \dots, n\,; i = 1, \dots, m$$ Relation (40)

Step 5: Find the ideal and counter-ideal solution

If the ideal solution is shown with A^* and the ideal solution with A^- is shown, then:

$$A^* = \{v_1^*, v_2^*, \dots, v_j^*, \dots, v_n^*\}$$ Relation (41)

$$A^- = \{v_1^-, v_2^-, \dots, v_j^-, \dots, v_n^-\}$$ Relation (42)

v_j^* is the best value of j criterion among all options and v_j^- is the worst value of criterion j of all options. The options in A^* and A^- represent the better and the worse, respectively.

Step 6: In this step, for each option, the distance from the ideal solution and the distance from the counter-ideal solution are calculated from the following relation, respectively:

$$S_i^* = \sqrt{\sum_{j=1}^{n} (V_{ij} - V_j^*)}^2$$ Relation (43)

$$S_i^- = \sqrt{\sum_{j=1}^{n} (V_{ij} - V_j^-)}^2$$ Relation (44)

In these relations, index j represents the desired criterion and index i represents the desired option.

Step 7: Calculate the similarity index

In this step, the similarity index is obtained from the following relation:

$$C_i^* = \frac{S_i^-}{S_i^* + S_i^-} \qquad \text{Relation (45)}$$

The value of the similarity index varies between zero and one. The closer the option is to the ideal, the closer the similarity index value will be to one. It is quite clear that if an option matches the ideal option, then its distance from the ideal solution is equal to zero and its similarity index is equal to one and if an option matches the counter-ideal option, then its distance from the counter-ideal solution is equal to zero and its similarity index is equal to zero. Therefore, to rank the options based on the value of the similarity index, the option that has the most similarity index is in the first rank and the option that has the lowest similarity index is in the last rank (Opricovic and Tzeng 2004, 2007; Ataei 2018; Ameri et al. 2018).

The Copeland method is a modified version of the Borda method. In this way, to rank the options, a square matrix of options was first formed. In this matrix, the numbers 1 and 0 (number one sign of dominance of another option and zero number of sign of one option over another) were calculated and the sum of the dominance in each row and the sum of the defeat in each column were calculated. Eventually the difference between defeat and dominance was calculated and the final ranking was obtained (Dortaj et al. 2019).

Results

The results of the selection criteria for Boolean logic are presented in Figs. 5 to 12. The results indicate that the highest percentage of land use (Fige. 8) for constructing the underground dam is related to the use of degraded forests, grassland, and the best geological formation (Fig. 9) is related to the quaternary formation.

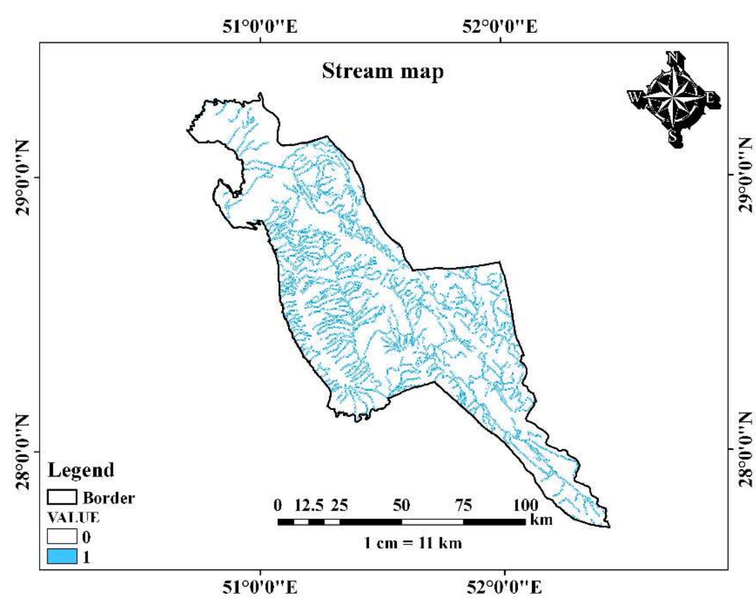

Fig 5. Boolean stream map of the studied area to locate underground dams

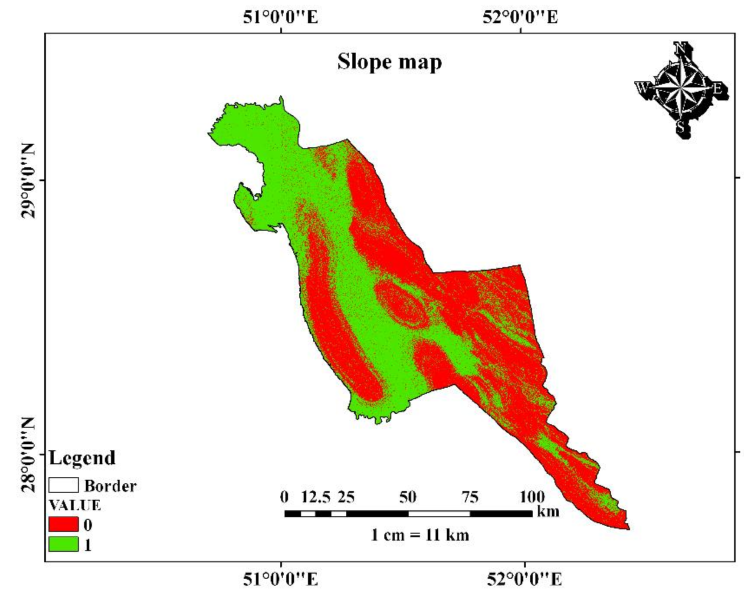

Fig 6. Boolean slope map of the studied area to locate underground dams

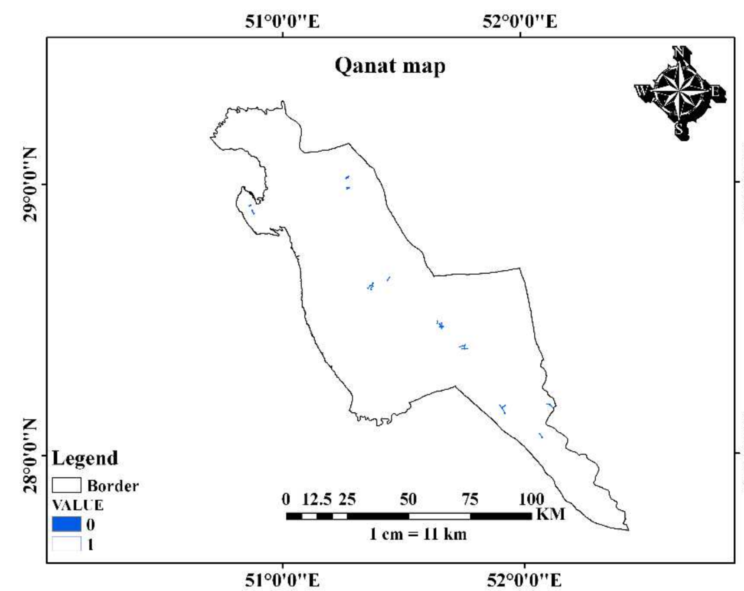

Fig 7. Boolean Qanat map of the studied area for locating the underground dam

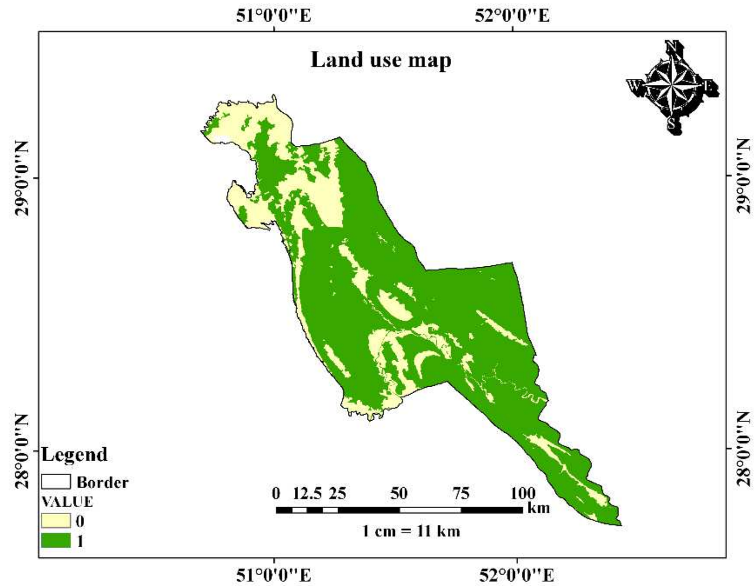

Fig 8. Boolean land use map of the studied area for locating the underground dam

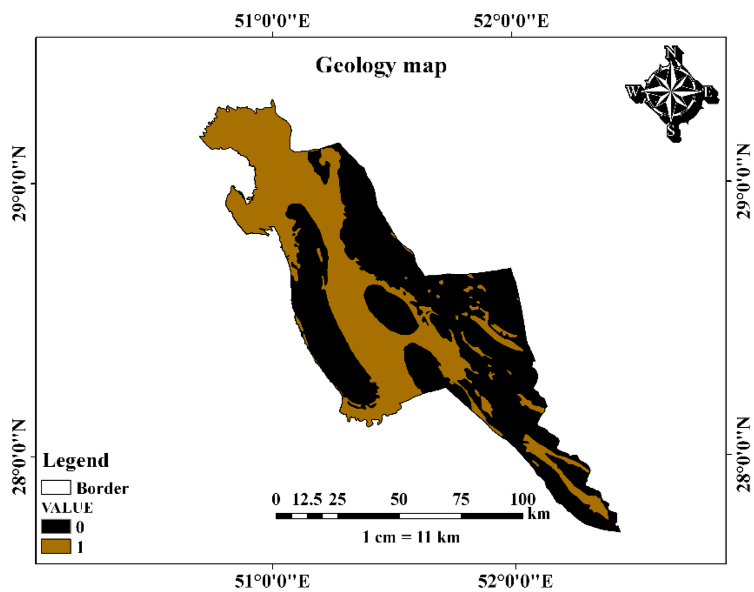

Fig 9. Boolean geology map of the study area for locating the underground dam

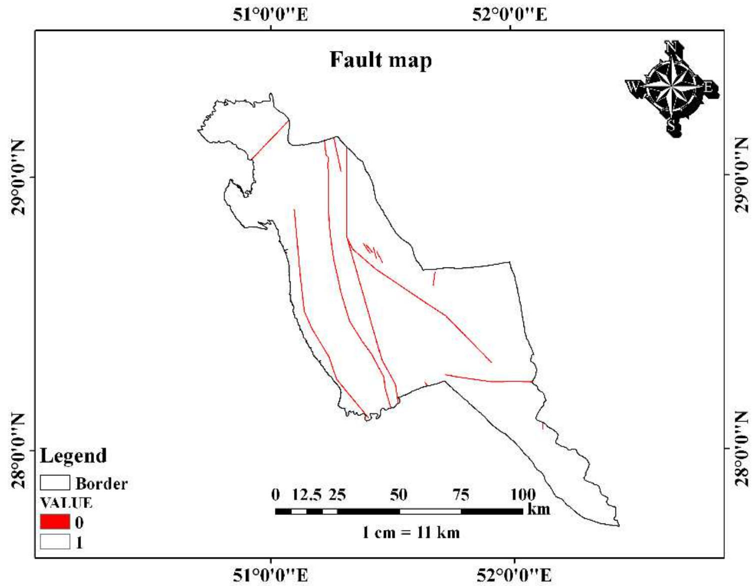

Fig 10. Boolean fault map of the study area for locating the underground dam

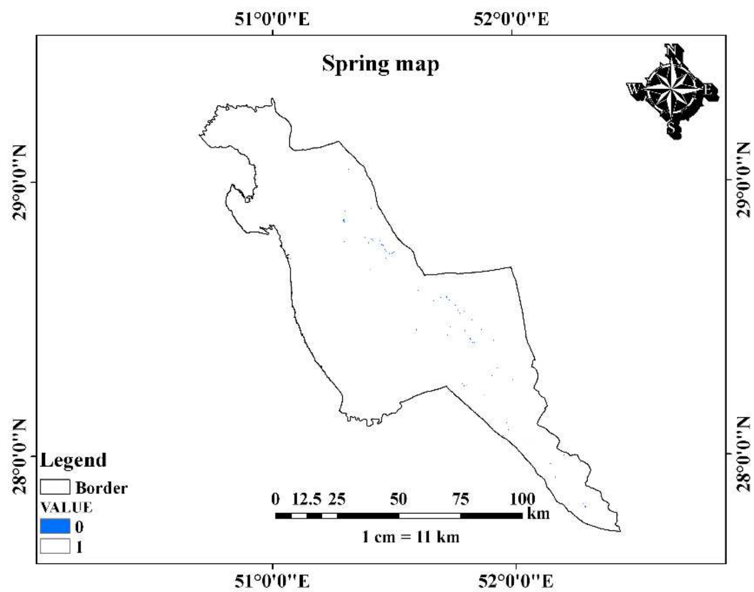

Fig 11. Boolean spring map of the study area for locating the underground dam

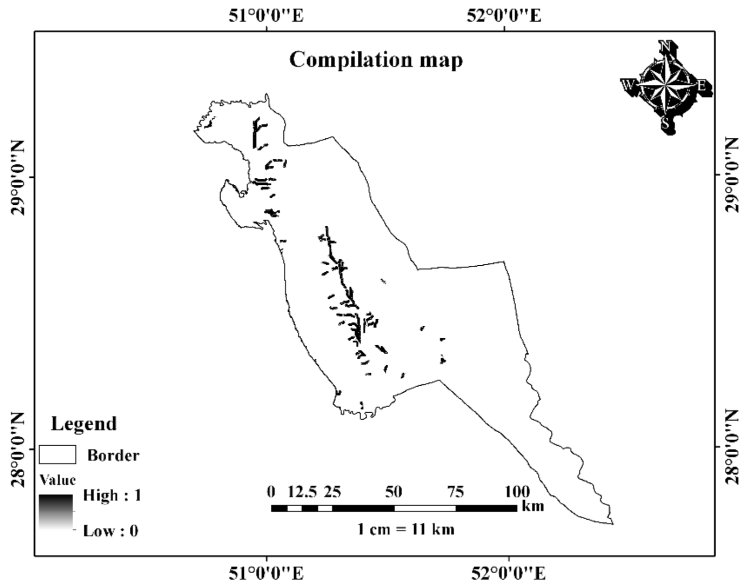

Fig 12. Appropriate area map of the study area for locating the underground dam

In this stage, the elimination method was used. The maps prepared in the elimination method shows that part of the study area in terms of initial criteria does not have the potential for underground dams. Therefore, these inappropriate areas have been excluded so that the remaining areas can be investigated more carefully. Then the map of the obtained by Boolean logic from the first step, overlaid by Google Earth images. Thus, out of the obtained zones, 23 axes were identified as potential axes for the construction of underground dams. A field visit was conducted to confirm the findings obtained from an eye visit to Google Earth images. Finally, with field visits, 6 sites were identified as suitable and potential sites for underground dam construction. The data were then entered into the AHP model. Paired comparisons were performed using Super Design software and the weights of the criteria were obtained. Controlling the inconsistency rate was performed and the inconsistency rate was less than 0.1. Then the weights obtained from the AHP model (Table 2) were entered into the ANP, TOPSIS, VIKOR and ELECTRE III models. In this study, not only MCDM methods practical used, but also the application of integration strategies to link the results of different methods. The Copeland method used in the present study reduces the uncertainty in the different results and provides a unique answer for choosing suitable locations for the construction of underground dams.

In this study, the results of ranking AHP, TOPSIS, ANP, VIKOR and ELECTRE III models and combining them with model Copeland are shown respectively in Tables 3, 4 and Figures 13.

Table 3. Prioritization of the sub-criteria in the AHP model

Row	Criterion	Weight	Row	Criterion	Weight
1	Quantity	0.49504	7	Water Requirements	0.15032
2	Quality	0.15157	8	Access	0.05736
3	Surface	0.00540	9	Depth axis	0.06132
4	Slope	0.01138	10	Length	0.02417
5	Depth	0.00345	11	Lithology	0.01398
6	Permeability	0.02594	-	-	-

Table 4. Ranking of places in the AHP, ANP, ELECTRE III, TOPSIS AND, VIKOR models and combining models with the Copeland

Name	AHP	ANP	ELECTRE III	TOPSIS	VIKOR	Copeland
Zayer Abbasi	1	1	2	2	2	1
Faghih Hasenan	4	6	5	5	6	6
Maqatel	6	2	1	6	5	5
Miyankhare	3	5	4	3	4	4
Kabgan	2	4	6	1	1	2
Gezdraz	5	3	3	4	3	3

The results of the Copeland model indicate that, Zayer Abbasi was in the first priority, Kabgan in the second priority, Gezdraz in the third priority, Miyankhare in the fourth priority, Maqatel in the fifth priority, Faghih Hasenan is in sixth priority (Fig. 13).

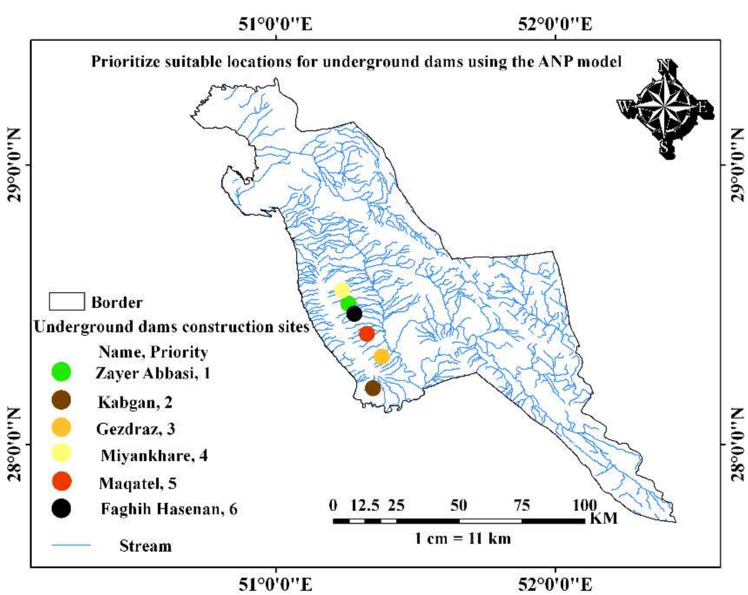

Fig 13. Prioritizing suitable locations in the studied area for the construction of an underground dam

Discussion

The results obtained from Tables 2 and 3 and based on expert opinion show that the quantity of water is more important compared to its quality, which is consistent with the results of Nilsson (1988), Talebi et al (2019), and Kharazi et al (2019). Also, because the geological characteristics are important in the quantity and quality of water storage, water quality is also an important criterion for water resources projects, which, if contaminated sources such as salt domes, industrial plants, etc. were eliminated at first which is consistent with the results of Barkhordari (2015), and Kharazi et al (2019). The more the stream has a more subsurface flow, the more important it is than the other waterways. The present study show that the most suitable channels for underground dams are the 3rd, 4th and 5th grade channels, which are consistent with the Farokhzadeh et al (2015), Talebi et al (2019), and Rohina et al (2019) results. In the underground dams, unlike surface dams, due to losses due to evaporation is considered a defect, the best location for the underground dam in a river is the best location for the underground dam in a river, which has the highest reservoir level in the upstream regions. According to the results of Tables 2 and 3 because the permeability has a significant effect on water flow and reservoir storage coefficient, this parameter is one of the important parameters in the construction of the underground dam, which is the most important factor in the reservoir indices, which are consistent with the Nilsson (1988), Foster and Tuinhof (2004), Barkhordari (2015), Talebi et al (2019), and Rohina et al (2019) results. This research also considered the most suitable reservoirs for streams with high permeability alluvial beds, low slopes and latitudes, and a suitable level and depth, which are consistent with the Dorfeshan et al (2014), Barkhordari (2015), Farokhzadeh et al (2015), and Kharazi et al (2019) research results.

Conclusion

The results showed that using Boolean methods to find suitable areas, AHP, TOPSIS, ANP, VIKOR, and ELECTRE III models and merging the models with the Copeland method to prioritize suitable areas for the construction of underground dams can improve the modeling accuracy to find suitable areas to build underground dams that are compatible, which are consistent with the Farokhzadeh et al (2015) and, Dortaj et al (2019) research results.

The results of prioritizing showed that the Zayer Abbasi area in the Copeland model due to its suitable supporting structure (Allerin formation (Dyke), thick alluvium (20 m) and coarse grains with high permeability, and the quantity and high water quality in the first place for construction The underground dam was studied in the region.

The overall conclusion is that in arid and low rainfall areas due to atmospheric conditions, evaporation is high and the possibility of storing surface water on a small scale is difficult and non-economic and may sometimes have adverse environmental effects. In these areas and where there are subsurface currents, there is the possibility of extraction and harvesting of water, one of the best practices for harvesting submerged currents is the use of underground dams (Chezgi et al. 2016a). As a result of the construction of underground dams in the southern regions of the country due to the presence of dry and semi-arid soils, irregular distribution of rainfall and the limitation of surface and underground water resources, the construction of underground dams is one of the effective ways to save water and to cope with drought in these areas it is stressed.

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Figures

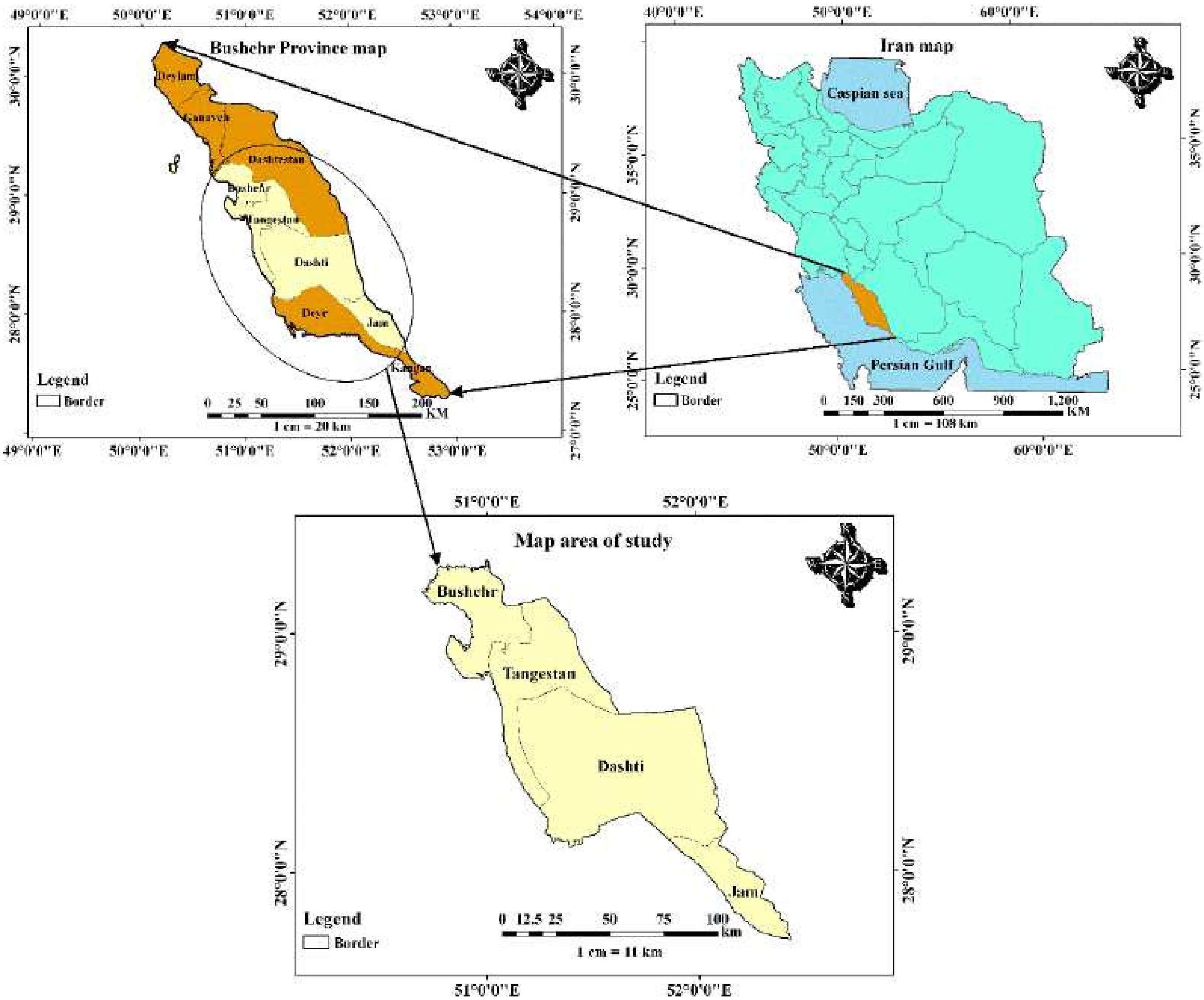

Figure 1

The map of the studied area

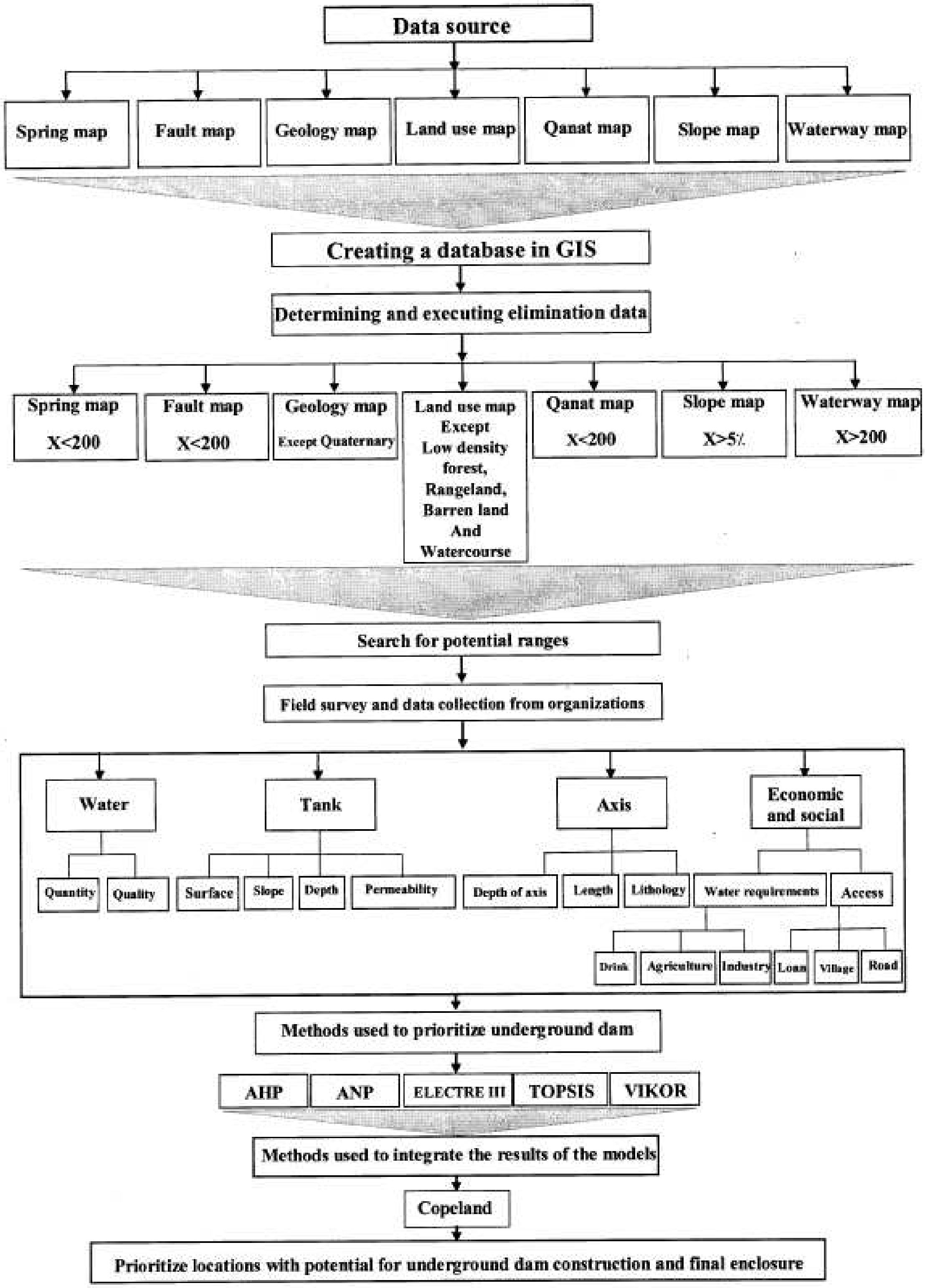

Figure 2

Flowchart of identification of appropriate areas for locating underground dam construction

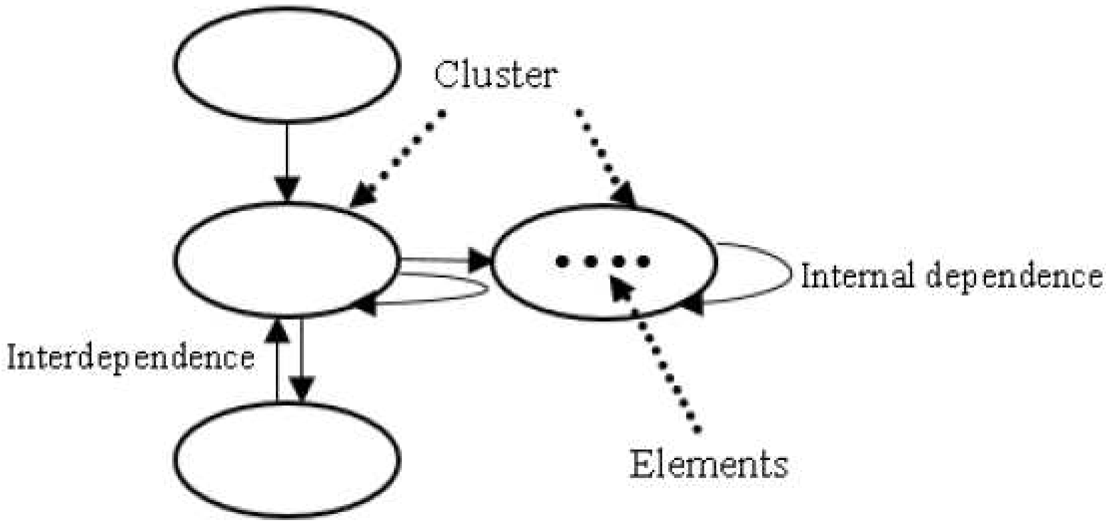

Figure 3

Network analysis method (Ataei 2018)

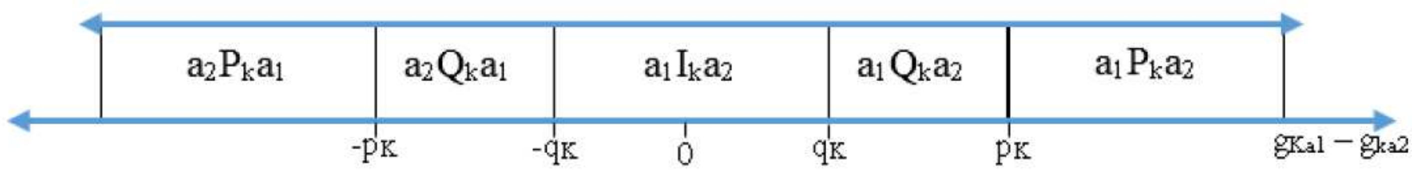

Figure 4

The concept of thresholds in ELECTRE III method (Ataei 2018)

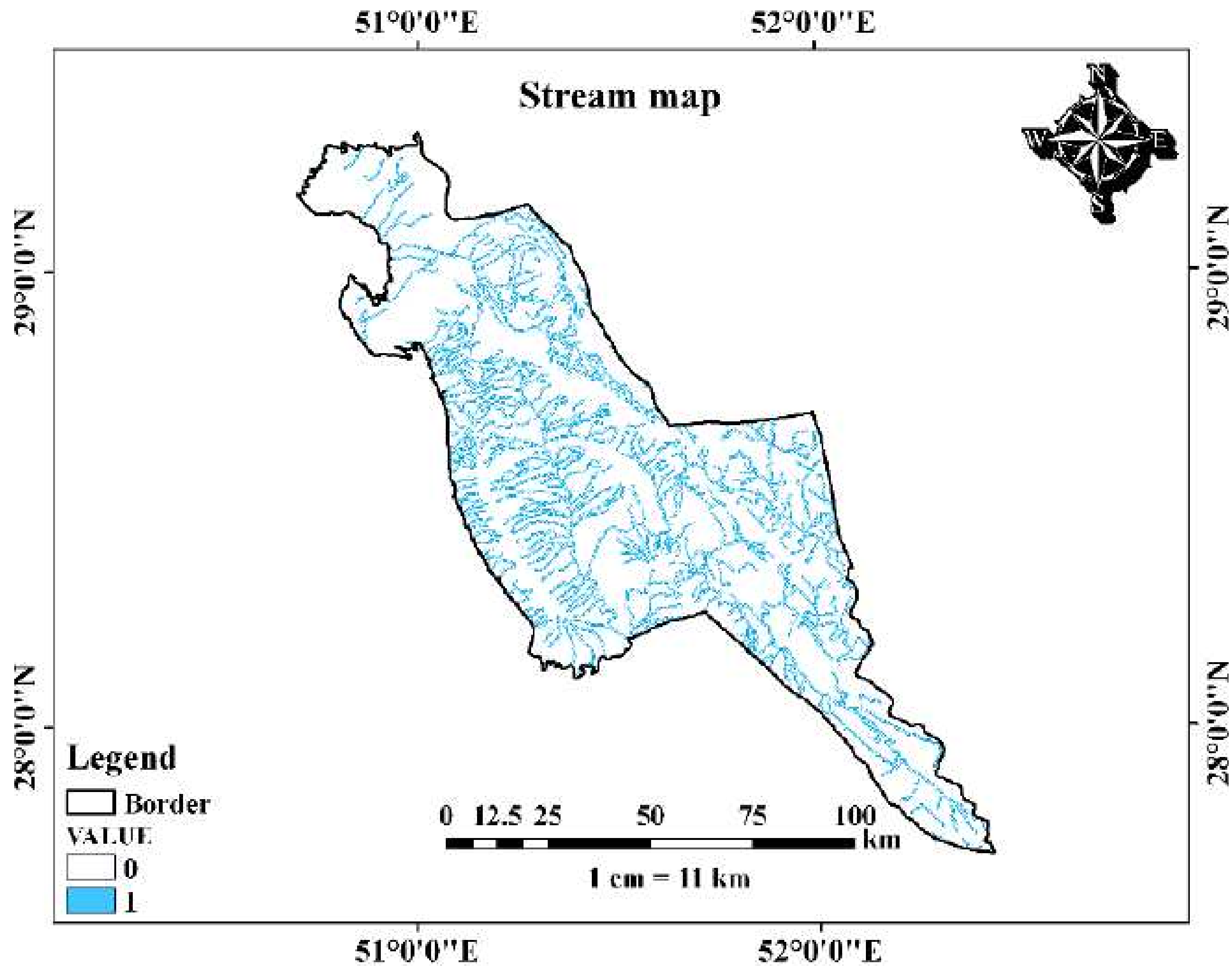

Figure 5

Boolean stream map of the studied area to locate underground dams

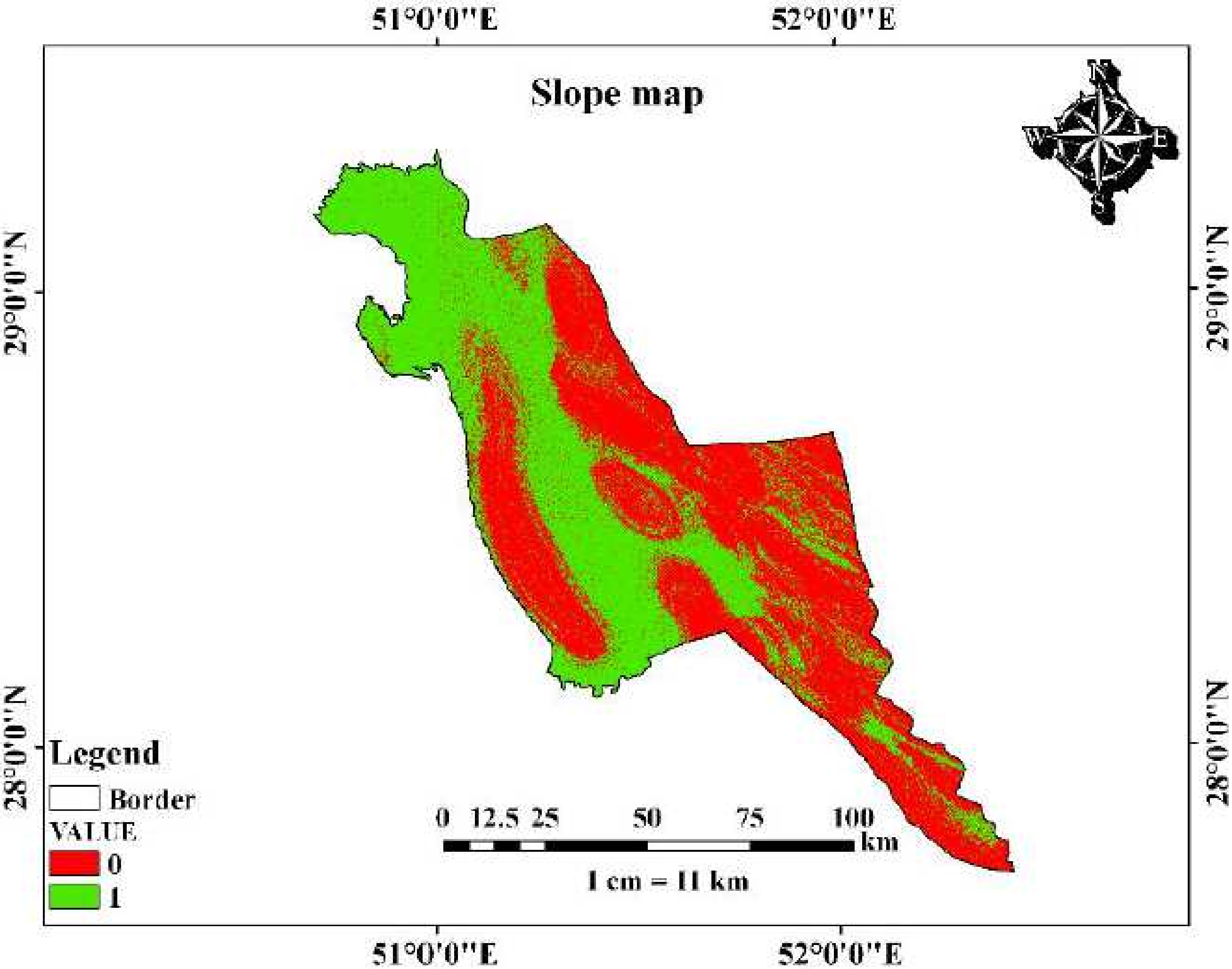

Figure 6

Boolean slope map of the studied area to locate underground dams

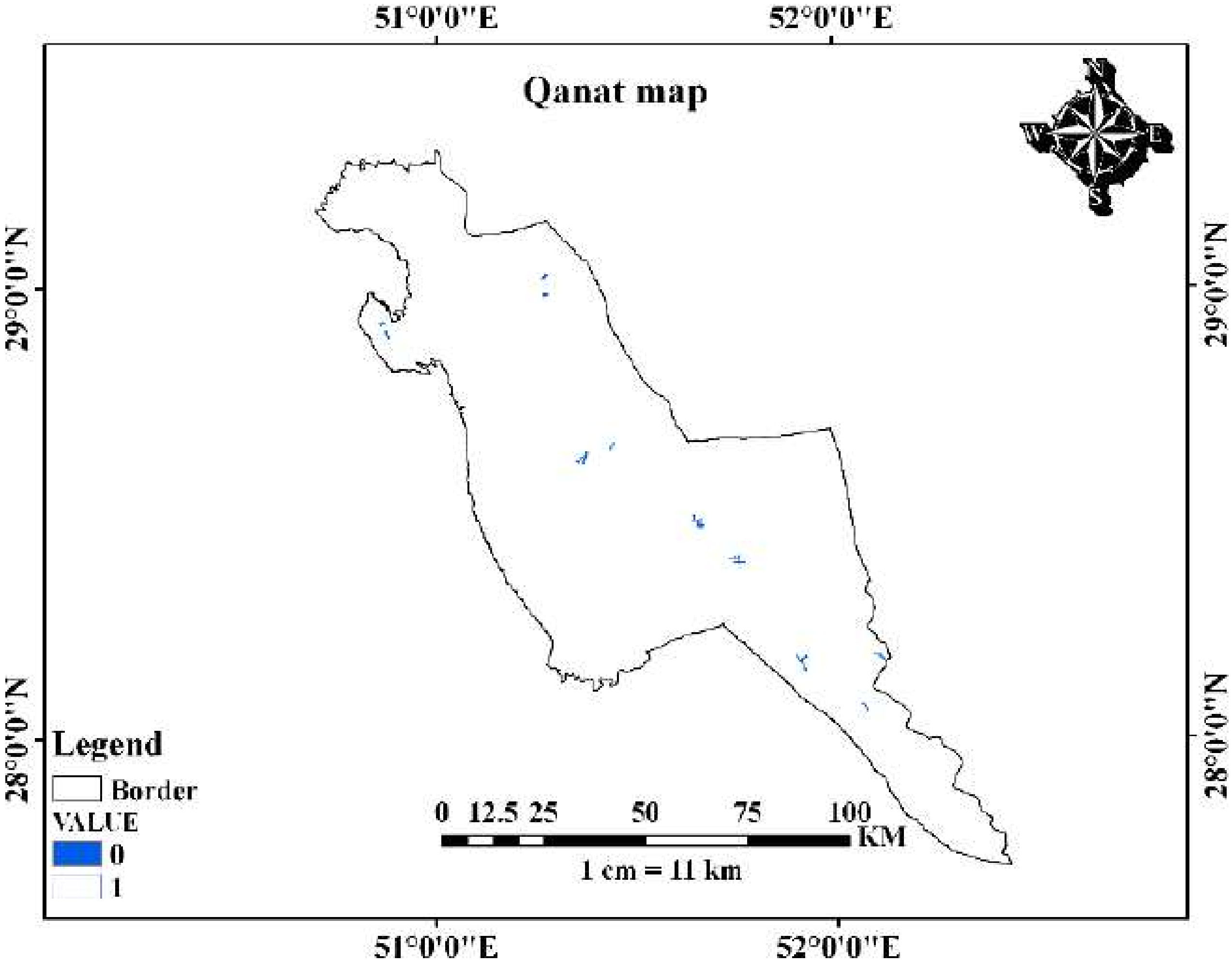

Figure 7

Boolean Qanat map of the studied area for locating the underground dam

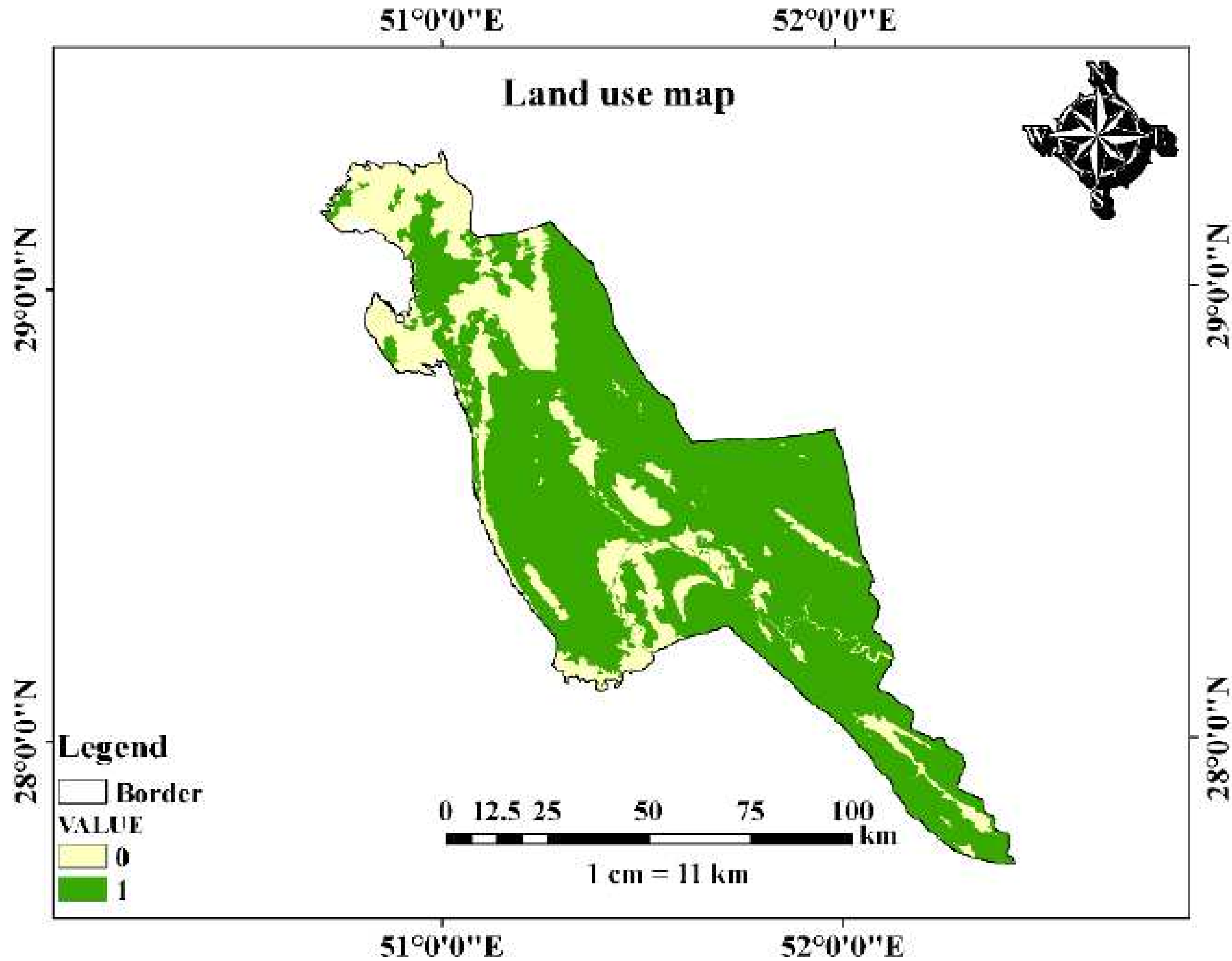

Figure 8

Boolean land use map of the studied area for locating the underground dam

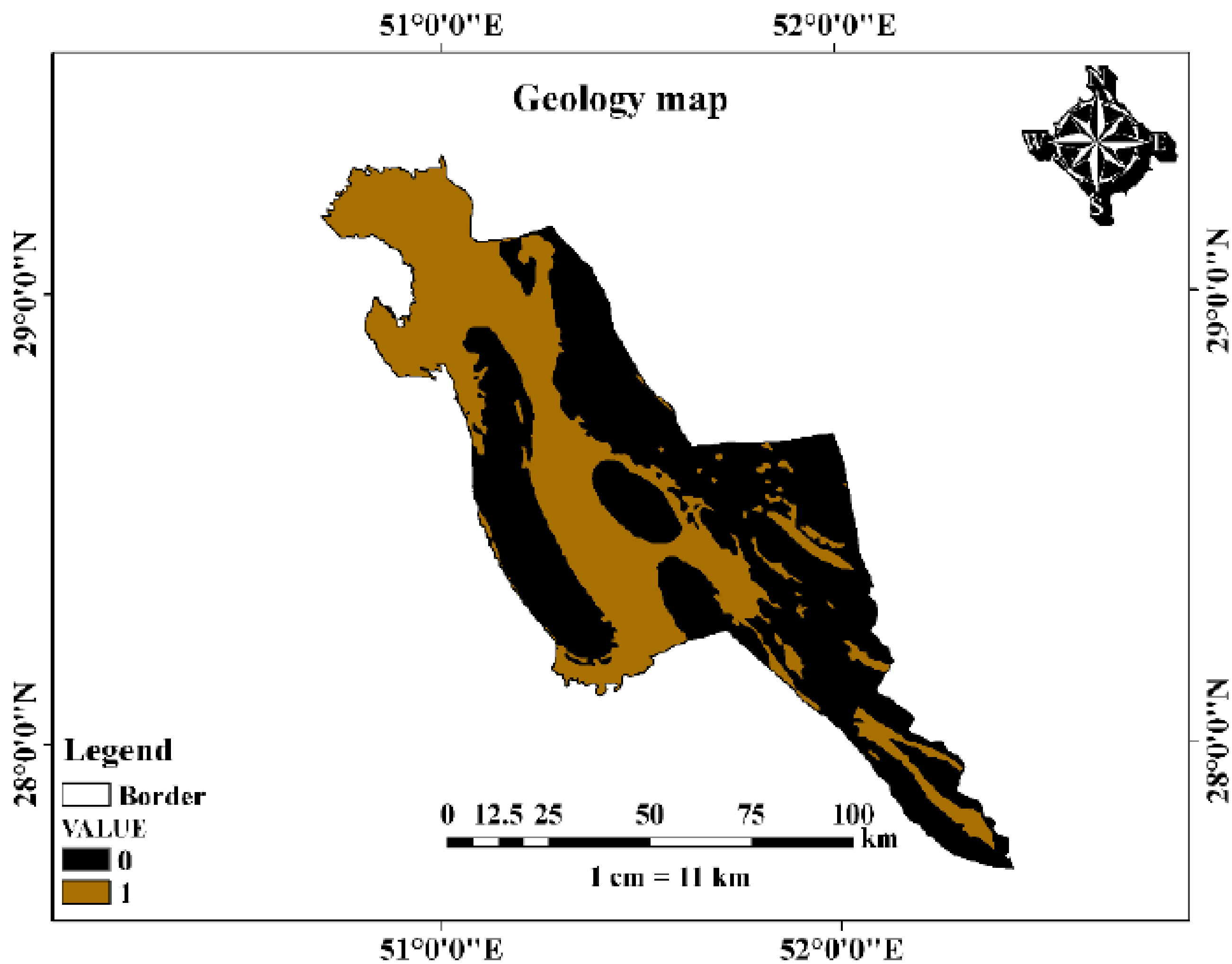

Figure 9

Boolean geology map of the study area for locating the underground dam

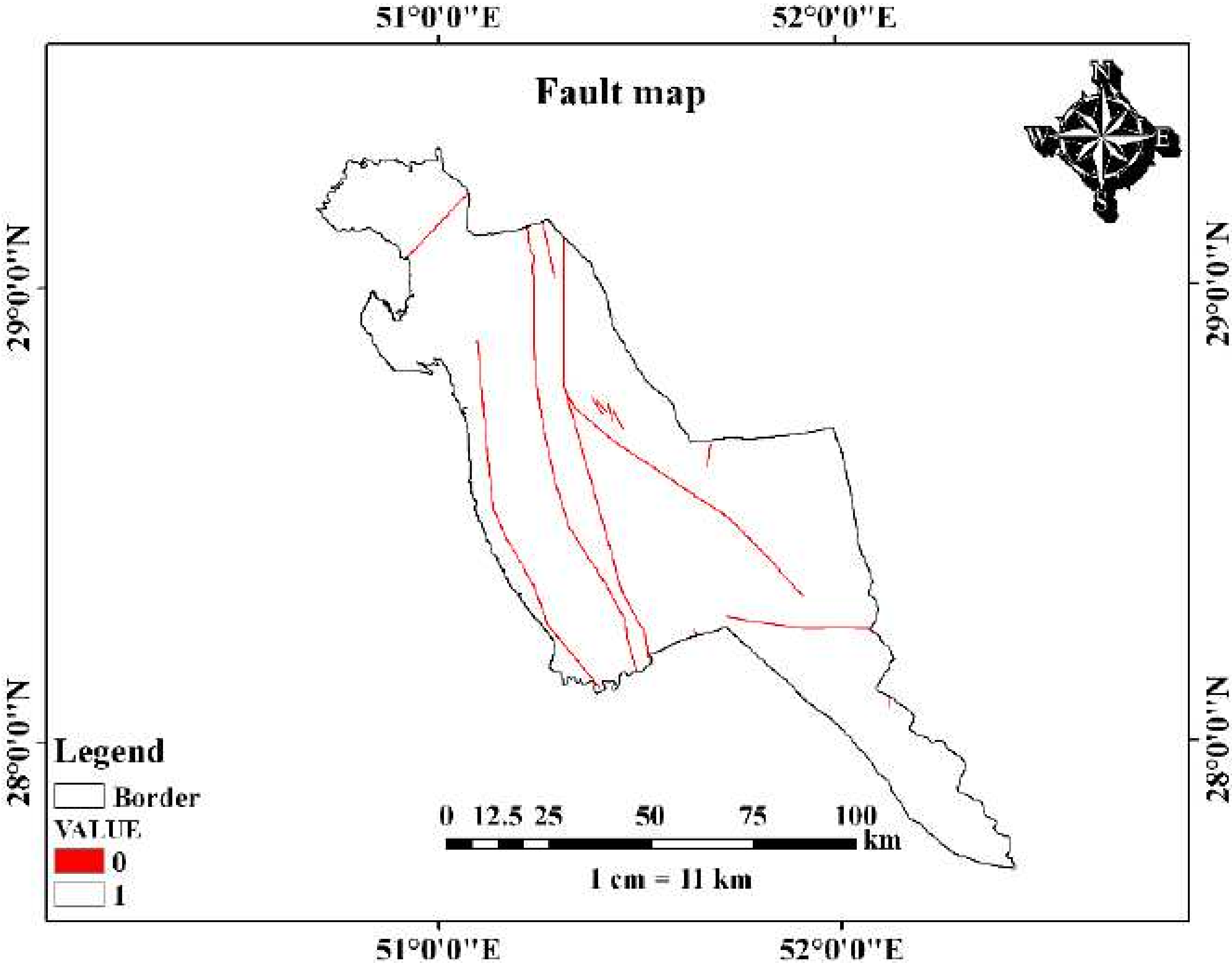

Figure 10

Boolean fault map of the study area for locating the underground dam

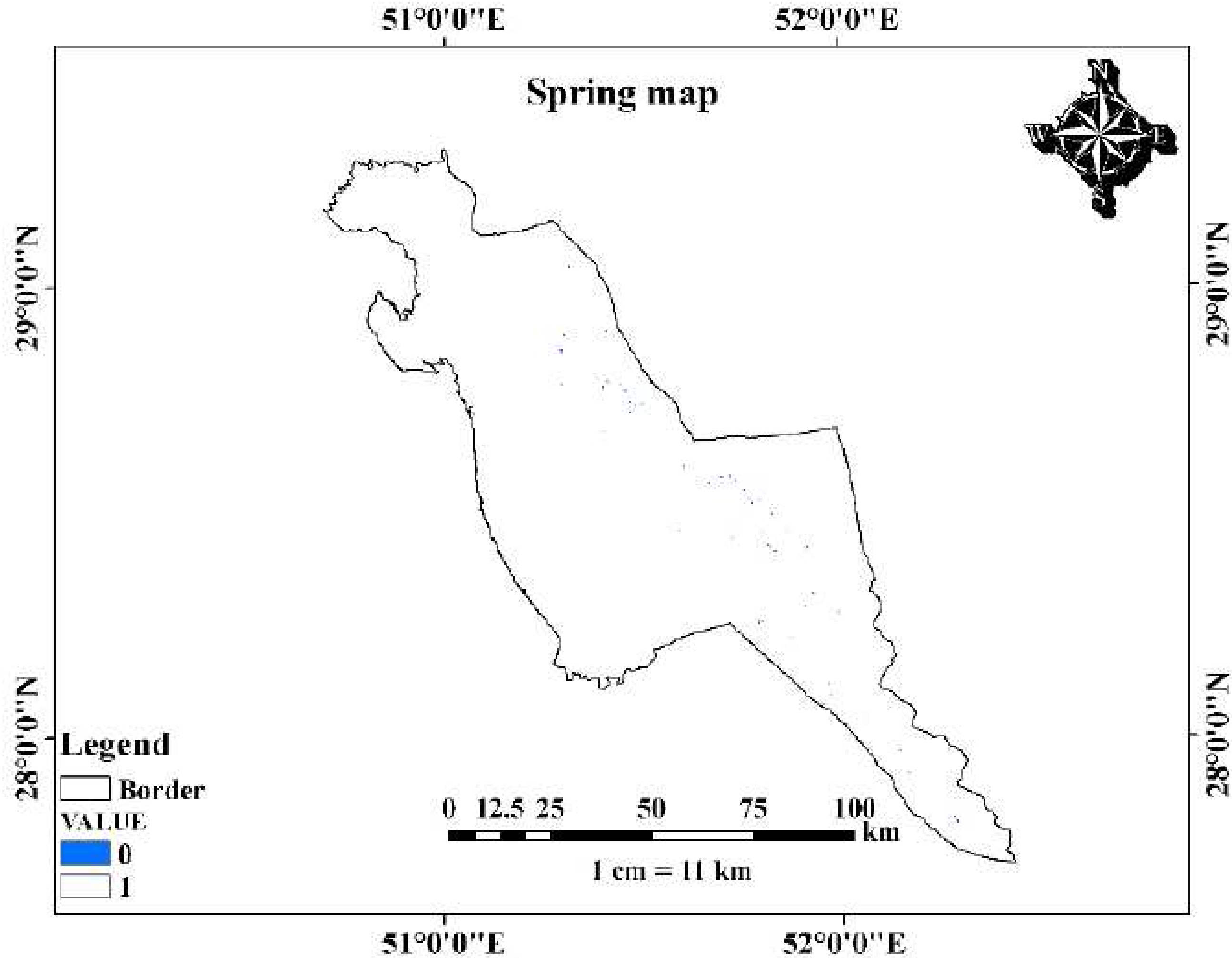

Figure 11

Boolean spring map of the study area for locating the underground dam

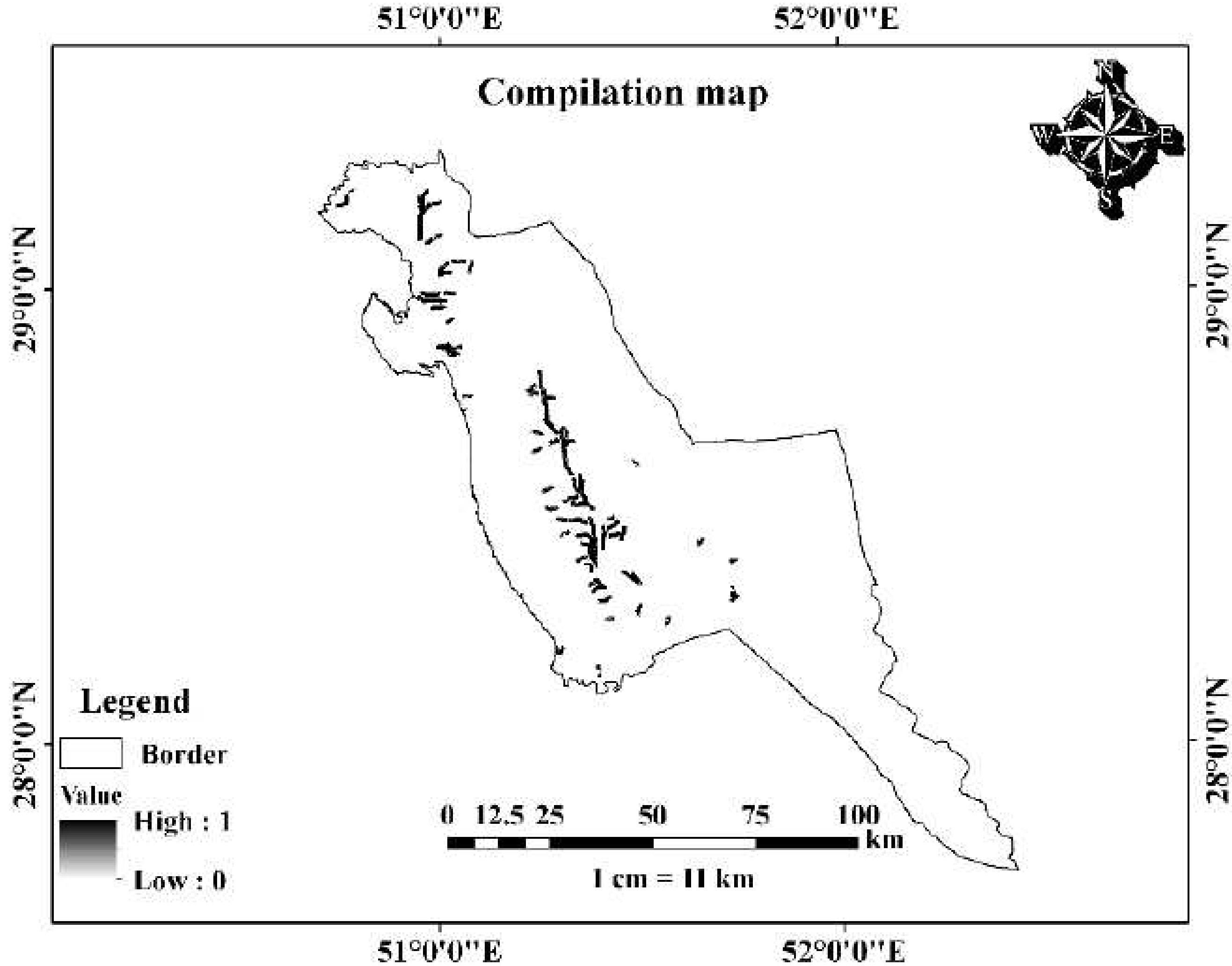

Figure 12

Appropriate area map of the study area for locating the underground dam

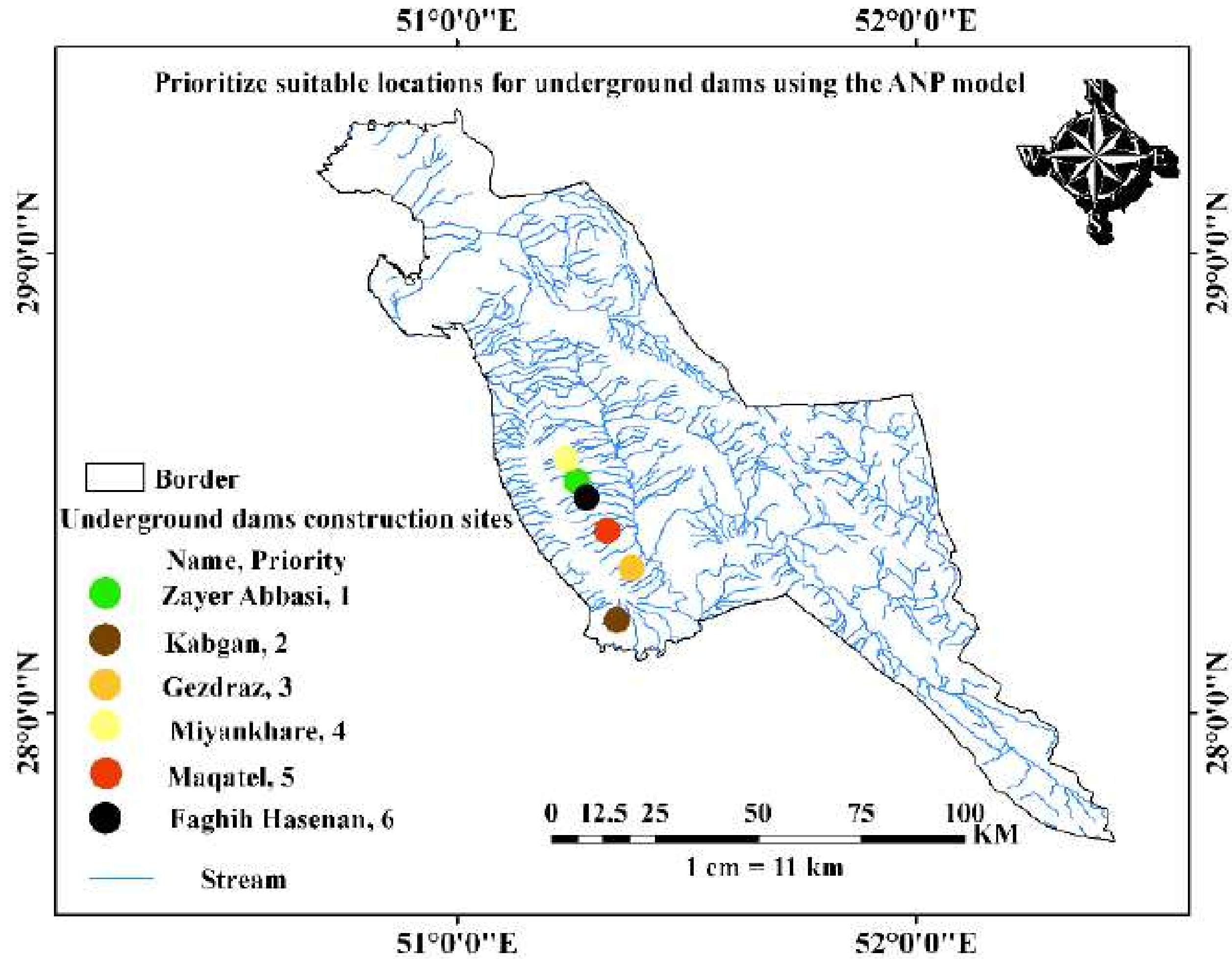

Figure 13

Prioritizing suitable locations in the studied area for the construction of an underground dam