Environmental Energy and Economic Research 2023 7(2): S060
DOI 10.22097/eeer.2023.370112.1272

Research Article

Gypsum Factory Site Selection in Qom Province using Different Multi-Criteria Decision Making Methods and Remote Sensing Techniques

Fahimeh Akbari [a], Afsaneh Afzali [a,*], Maliheh Abbaszadeh [b]

[a] Department of Environment, Faculty of Natural Resources and Earth Sciences, University of Kashan, Kashan, Iran
[b] Department of Mining Engineering, University of Kashan, Kashan, Iran

Received: 6 November 2022 /Accepted: 8 January 2023

Abstract
The purpose of this research is the site selection of the gypsum factory in Qom province by considering the effective criteria using different multi-criteria decision making methods and remote sensing techniques. Satellite images processing methods such as the false color composite method, band ratio method, and selective principal component analysis (CROSTA) method were used to find the possible location of the presence of minerals related to gypsum industries and the possible locations of the presence of the desired minerals were determined. Then, the location map of open pit mines was formed by their geographical coordinates, which were entered into the GIS along with other layers of criteria in a similar format and standardized by fuzzy logic. Then the criteria were weighted using the analytic hierarchy process method. According to the results of weighting using the analytic hierarchy process method, it was determined that the distance from gypsum mines and distance from industries were introduced as the most important (0.231) and least important (0.021) criteria, respectively. After applying the minimum required area, 4 regions with an area of 203 hectares were identified in the southern parts of Qom, Kahak, and Salafchegan cities. Also, by prioritizing 4 suitable options for the establishment of the industry using the fuzzy TOPSIS method, option 1 with an area of 23886 hectares in the Salafchagan sector was determined as the best option. The methods used in this study can provide decision-makers with possible options and prevent the complications of the inappropriate establishment of the relevant industries.
Keywords: Site selection, Gypsum industry, Weighted linear combination, Fuzzy TOPSIS, Satellite images processing.

Introduction

The new issue that has attracted the attention of researchers and governments in the last few years is the issue of site selection for the establishment of industries and prevention of environmental crises, as well as the sustainable use of all the facilities of the land (Jaafari and Karimi, 2014). Finding the optimal level in which, in addition to creating employment, increasing production, reaching self-sufficiency, increasing gross income, etc, the environment and the people living in it will not be harmed, or the damage and destruction will be reduced to

* Corresponding author E-mail: a.afzali@kashanu.ac.ir

a normal level, is important. Also, in addition to the economic benefits, it would reduce the abnormal effects that this use can have on the environment and take into account its political and social dimensions. Therefore, the issue of site selection is considered an essential part of land development plans (Khaliji and Saeedeh Zarabadi, 2015).

Various criteria have been used by researchers in locating industrial units. For example, effective factors such as access to raw materials, energy, transportation, labor, water, and market (Tiwari, 2014, Ravix, 2014), as well as regional demand, regional production costs, regional policies, economic density, market size, potential labor market, and the wage level of the production sector are among them (Guzman, 2015). In the meantime, the government's policies move more towards investigating environmental degradation and reducing industrial density (Tiwari, 2014). In other words, the climatic and environmental characteristics of the region and the density of specific industries have become more important for selecting a location (Guzman, 2015). Due to the technical problems and the cost of transporting the minerals extracted from the mine and the traffic caused by the traffic of trucks transporting the materials, the suitable site for the ore processing units is chosen near the respective mines (Rahmani, 2014, Ataei, 2005).

Gypsum is natural hydrous calcium sulfate and occurs in several crystalline forms, often in the form of relatively thick crusts in deposits of the earth's solid crust. Gypsum is used in construction, sculpting, casting, cement making, and pharmaceutical industries, and it is also needed in medical works for fracture (Akbarzadeh et al., 2010). Gypsum is one of the important sources of air pollution in urban areas, which pollutes the city's air by destroying the soil texture. Also, during the preparation of gypsum, 1 ton of gypsum enters the environment in the form of dust from every 10 tons of gypsum. Therefore, organizing gypsum preparation units is essential (Hadad, 2015).

Determining the appropriate location of industrial activities is a very complex decision and depends on a wide range of criteria, most of which depend on the existing conditions of access to the country's resources and also differ based on factors such as the type of industry. Therefore, this problem is considered a multi-criteria decision-making process (MCDM) in which different criteria are prioritized and the best option is selected from among the possible options (Reisi and Soffianian, 2010, Atthirwang and MacCarthy, 2001).

Multi-criteria decision-making includes methods that cause decision-makers to make decisions based on different and sometimes conflicting criteria. It can be said that multi-criteria decision-making makes it possible to investigate complex problems by breaking down the problem into smaller components. After examining and deciding on the smaller components, these components are reassembled and show the general tendencies of the decision makers (Deng, 1999). The decision-making steps in the multi-criteria decision-making analysis method include defining the decision-making problem, determining the criteria required for analysis, weighting, and combining the criteria (Linkov et al., 2006). The analytic hierarchy process (AHP) is one of the most comprehensive weighting methods in decision making. In this method, quantitative and qualitative criteria are used to make complex decisions and it is based on the three principles of analysis, comparative judgment, and combination of priorities (Ghodsipour, 2010).

One of the superposition methods is the weighted linear combination (WLC). The weighted linear combination method is the most common technique in multi-criteria analysis and evaluation, which is also called the scoring method and is based on the concept of weighted average. The decision maker gives weights to the criteria based on the relative importance of each criterion. Then, by multiplying the relative weight by the value of that feature, a final value for the option is obtained, and finally, the option with the highest value will be the most suitable (Parhizkar and Ghafari Gilandeh, 2006).

To combine effective criteria in site selection, all criteria need to be standardized on the same scale. Fuzzy logic can be used to standardize information layers. There is a fuzzy nature to a large extent in the existing criteria in site selection (Aronoff, 1989, Afzali et al, 2014). In this method, each layer of the problem is graded on a scale between 0 and 1, in which larger numbers are more desirable (Madadi et al., 2013). Also, in this method, all the rules have a degree of correctness or incorrectness in them which affect the final result (Razavi et al., 2015).

One of the multi-criteria decision-making methods that is used in the ranking of options is the TOPSIS method in a fuzzy environment. Ranking in the TOPSIS method is based on the degree of closeness to the ideal answer (Opricovic and Tzeng, 2004). In the TOPSIS method, the best option should have the smallest distance from the ideal solution and the largest distance from the anti-ideal solution. This method introduces two ideal and anti-ideal points, and the relative importance of the distances from these two points is considered by combining it with the fuzzy method (Chu et al., 2007). The availability of raw materials is one of the criteria related to the location of the gypsum industry, because the movement of raw materials causes the dispersion of particles. Therefore, to reduce transportation costs and prevent the dispersion of dust particles caused by the movement of raw materials, the gypsum industry should be located near the relevant mines (Torabi, 2011).

Today, remote sensing methods are also used to locate industries. Remote sensing is the science of obtaining, processing, and interpreting satellite images and data without direct contact with exploration targets on the surface of the earth. Satellite images that are obtained through remote sensing satellite sensors record the interaction of matter and electromagnetic energy and play an important role in the exploration of investigated areas, including mineral areas, vegetation, water areas, etc. Therefore, it is possible to obtain the information needed to identify the desired areas by using the images of different sensors and using different algorithms of satellite image processing (Gabr, 2010, Sabins, 1999, Asgari et al., 2014).

Regarding the site selection of industries in the world, some researches have been done. Tesani (2013), taking into account 11 effective criteria, has addressed the location selection of a cement factory in Indonesia using AHP. Also, Chabra (2015), using multi-criteria analysis decision-making and geographic information system (GIS), located a cement factory. In Iran, we can refer to Jafari and Kalantari (2013) regarding the investigation of the best cement factory in terms of location, where the researcher located 15 factories in different regions of Iran using the FAHP method and according to the 5 criteria of land, water, electricity, fuel, and transportation. Shafaei et al. (2013), in the study of the development of fuzzy TOPSIS based on the principles of sustainable development (case study: Mashhad iron smelter) by determining 20 criteria and weighting them, ranked the options using the fuzzy TOPSIS method and their results showed that Tous Industrial Town is a suitable place to build an iron smelting plant in Mashhad.

However, the studies carried out in the field of site selection of industries considering the importance of specific industries have rarely been done and if any study has been done with an emphasis on the location of a specific industry, the role of the criterion of access to raw materials of that industry has been neglected. With a new approach, this study has taken advantage of remote sensing capabilities to find the mineralization ranges of clay minerals to determine the relevant criteria for locating the gypsum factory in the Qom province.

Material and Methods

The study area

Qom province with an area of 11240 km2 is located between 34°15′ and 35°15′ north latitude and 50°30′ to 51°15′ east longitude (Figure 1). Qom province is adjacent to Tehran, Semnan, Isfahan, and Markazi provinces and is located in the central part of Iran. Qom province has considerable capabilities in the field of industry and mining in terms of mineral deposits such as limestone and building stones. Also, due to the proximity of this province to large consumption markets and being on the main communication routes of the country, and being outside the radius of Tehran's investment ban, it is suitable for building factories.

Method

In this study, the used criteria include slope, distance from wells and springs, distance from surface water, depth of underground water, distance from power transmission lines (electricity and gas), distance from communication ways (railway and asphalt), distance from industries, land use, distance from residential areas and agricultural lands and access to raw materials (gypsum), distance from faults and distance from a protected area as well as wind direction.

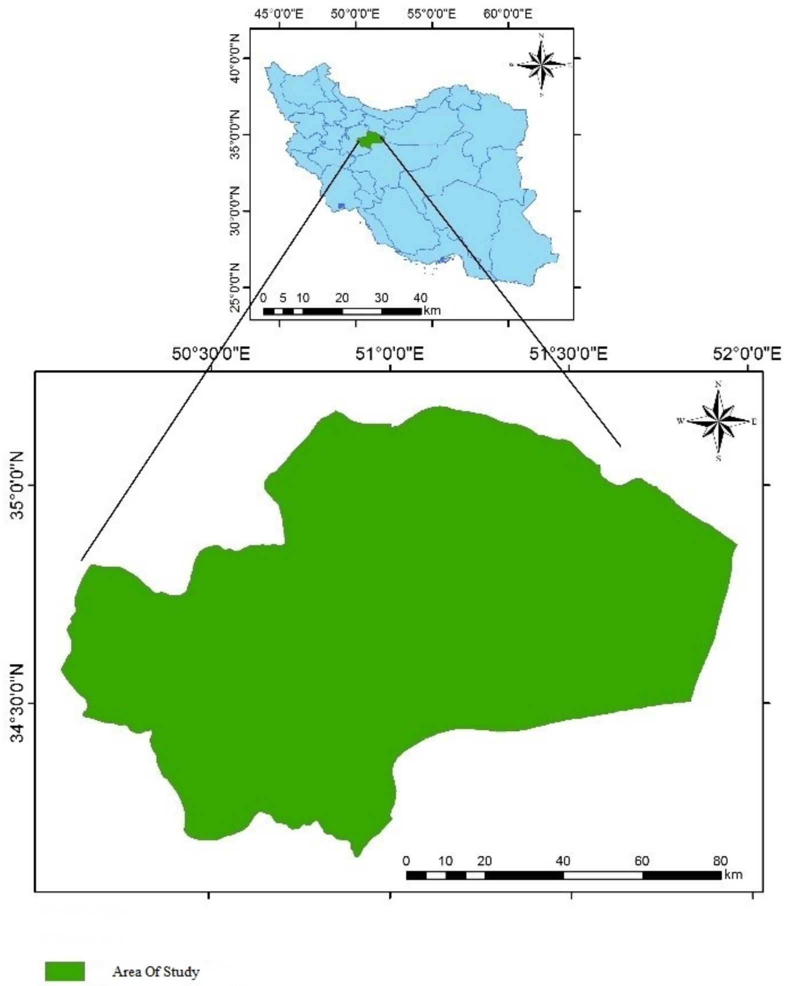

Figure 1. The location of the study area in Iran

After determining the effective criteria for locating the gypsum industry, spatial layers related to each criterion were created. To compare the criteria, it is necessary to standardize them in a specific format. This was done using fuzzy logic. Considering that one of the influential criteria in locating gypsum mining industries is access to raw materials, to find the location of raw materials in relation to the relevant mines, remote sensing capabilities were used in the Envi:4.8 software environment. Therefore, after finding the location of mines and possible areas of mineralization, the relevant layer was included as one of the effective criteria in the superimposition. To weigh the criteria, the analytic hierarchy process (AHP) was used. Then, the weighted linear combination (WLC) method was used to combine and superimpose the criteria. After finding suitable areas using the WLC method, they were ranked by the fuzzy TOPSIS method.

Remote sensing processing

Remote sensing techniques have been used to obtain a distribution map of mines related to gypsum industries. First, by using image processing methods, places with gypsum mineralization potential were identified. For this purpose, the methods of false color composite, Band ratio, and Crosta have been used.

In this study, to identify potential areas for gypsum mineralization in Qom province, Landsat 8- OLI satellite images have been analyzed using different processing methods. The characteristics of different bands of Landsat 8 OLI sensor are given in Table 1.

Table 1. characteristics of OLI sensor bands of Landsat 8 satellite (Abhari, 2015)

Spectral band	Wavelength	Spatial resolution
Coastal/Aerosol Band1-	0.433 – 0.453 µm	30m
Band2- Blue	0.453 – 0.515 µm	30m
Band3- Green	0.525 – 0.600 µm	30m
Band 4- Red	0.630 – 0.680 µm	30m
Band 5 - near infrared	0.845 – 0.885 µm	30m
Band 6 - short wavelength infrared	1.560 – 1.660 µm	30m
Band 7 - short wavelength infrared	2.100 – 2.300 µm	30m
Band 8 - Panchromatic	0.500 – 0.680 µm	15m
Band 9- Cirrus	1.360 – 1.390 µm	30m

False color composite method (FCC)

The use of colors provides us with a lot of visual and conceptual information. Since most satellite images are available in the form of multiple bands, single band analysis alone can not provide useful visual information. The use of this method is common in the preparation of color composite images in which three bands of red, green, and blue are used. In this study, RGB 752 combination has been used to display various complications in the image for visual processing using the false color combination method (Figure 2).

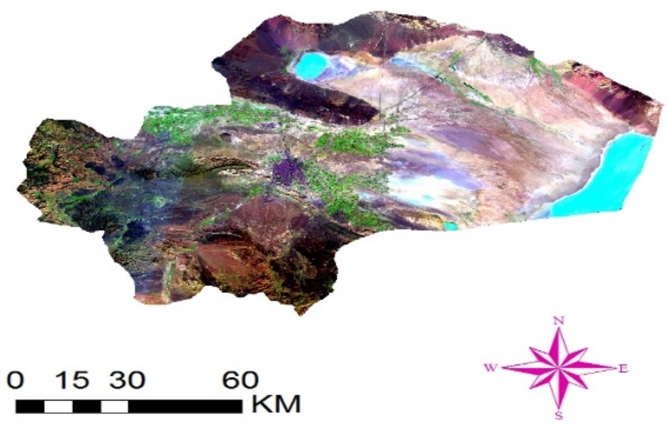

Figure 2. The image of the study area using RGB 752 false color composite method

Band ratio method (BR)

In the band ratio method, by knowing the characteristics of the absorption-reflection spectrum of minerals using the spectral behavior curve, the bands with the most reflection and absorption are selected to identify different minerals. In this method, the ratio of the band with the highest reflection to the band with the highest absorption is used to highlight different minerals (Gupta, 2003).

This method is also used to highlight the spectral difference between bands and reduce the effects of shadow and topography in images (Sabins, 1999). In this study, the band ratio of 6 to 7 was used to identify areas with gypsum in Qom province. Figure 3 shows the potential areas for gypsum mineralization in the studied area. Regions with bright pixels indicate target areas (Areas with clay minerals).

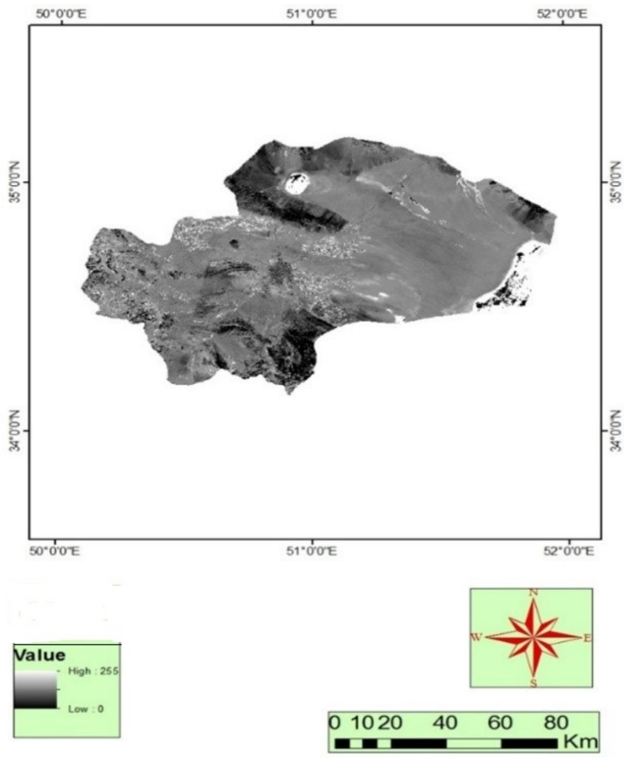

Figure 3. Representation of potential areas for mineralization of clay minerals in the study area using the band ratio of 6 to 7

Selective principal component analysis method (Crosta)

Sometimes, due to the increase in the volume of information, calculations become time-consuming and complicated, and the error in the process of doing the work increases. In such cases, principal component analysis is used. Therefore, the main purpose of using this method is to reduce the dimensions of the data set, while preserving their contained information (Su et al., 2005). Regarding satellite data, the dimensions of the problem are determined by the number of bands. Therefore, based on the bands that have high absorption and reflection for various exploration targets, it is possible to reduce the dimensions of the problem only by keeping these bands and discarding other bands. In this study, due to the high absorption and reflection of clay minerals in bands 7 and 6, respectively, the selective principal component analysis method was used to identify clay minerals. Based on this, principal component analysis has been applied only to four bands of 2, 5, 6, and 7.

Table 2 shows the list of eigenvalues and eigenvectors resulting from the analysis of selective principal components on the image of the studied area. Figure 4 shows the presence of clay minerals based on the image obtained from PC4. Regions with bright pixels represent areas with potential mineralization of clay minerals in the study area.

Table 2. Matrix of eigenvectors for selective principal components analysis method on 4 bands of OLI sensor in the image of the studied area

The principal components	Eigenvectors				
	Band 2	Band 4	Band 5	Band 6	Band 7
PC1	-0.408	-0.403	-0.400	-0.414	-0.416
PC2	-0.326	-0.273	-0.263	0.473	0.659
PC3	0.480	0.056	-0.783	-0.222	0.216
PC4	0.373	-0.412	0.391	-0.530	0.434
PC5	-0.459	0.634	-0.005	-0.496	0.371

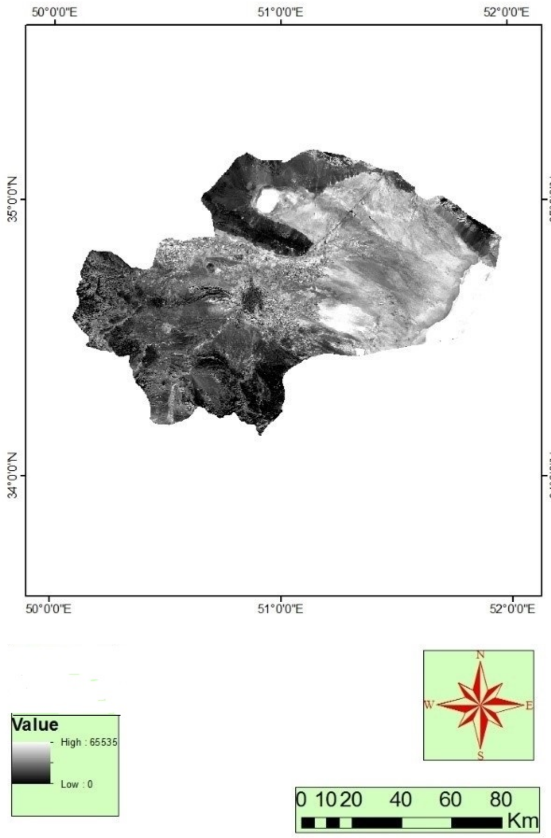

Figure 4. The presence of clay minerals based on the image obtained from PC4 in the study area

Standardization of layers by the fuzzy logic method

In the fuzzy logic method, to choose a suitable place for establishing a gypsum factory, first the layers were entered into the IDRISI-Terrset environment for standardization, and then the areas were given a value between zero and 255 based on the degree of suitability for establishing the factories. The closer the numbers are to 255, the more desirable they are. The threshold limit and type of fuzzy function for effective criteria in gypsum factory site selection are given in Table 3.

Table 3. Threshold limit and type of fuzzy function for standardizing criteria maps using fuzzy logic (Omidi, 2017)

Criteria	Control points in the functions				Fuzzy function name	Fuzzy function type
	A	B	C	D		
Distance from gypsum mine	*	*	0	20000	Decrease	Sigmoidal
Distance from surface water	500	1600	*	*	Increase	Linear
Distance from the well and spring	250	1600	*	*	Increase	Linear
Groundwater depth	250	1600	*	*	Increase	Linear
Distance from power transmission lines	*	*	250	55587	Decrease	Sigmoidal
Distance from communication routes	0	150	5000	50636	Increase	Linear
Distance from residential areas and agricultural lands	1500	51135	*	*	Increase	Linear
Slope	*	*	0	10	Decrease	Sigmoidal
Distance from industries	3000	38878	*	*	Increase	Linear
Landuse	Defined by the user, residential areas, agricultural lands, gardens, water 0, semi dense pastures 60, low density pastures 80, desert 150, barren lands 255					

Weighting of criteria

One of the methods of weighting the criteria is the analytic hierarchy process (AHP), which is used in studies related to decision-making. In this research, the AHP method has been used to weigh the criteria. After determining the effective criteria for locating the gypsum factory, a hierarchy diagram was made. Then the criteria were compared two by two in pairwise comparison matrices and the weight of each criterion was assigned in comparison with other criteria according to the priority level. Scoring was done based on expert opinion by environmental and mining experts (nine people) through questionnaires. After completing the questionnaires and calculating the final score, the criteria tree was formed in the Expert choice software and the applied scores were entered into the software. Finally, the final weight of each criterion and also the inconsistency coefficient were determined by Expert choice software.

Superimposing of criteria

In the weighted linear combination method, the fuzzy map of some criteria (distance from gypsum mines, distance from residential areas and agricultural land, distance from surface water, distance from well and spring, distance from road, depth of underground water, distance from industries, distance from power transmission lines, slope and land use) as factor maps and Boolean maps of some criteria (faults and protected areas) as constraint maps were entered into the IDRISI software environment. Then, using the MCE menu and the WLC option in the software, the constraints map, and the factors map were combined by considering the weight of the factors obtained by the AHP method. The resulting map of this overlay showed the suitable areas for the establishment of the gypsum factory in four levels: completely unsuitable (0-63), unsuitable (63-130), suitable (130-190), and completely suitable (190-255). So that the higher value in this method indicates the higher suitability of the site for the establishment of gypsum industries.

Ranking of options using the Fuzzy TOPSIS method

In this method, m options are evaluated by n indicators and prioritization of options is done based on similarity to the ideal solution. The basis of this method is that there is the least distance between the chosen alternative and the positive ideal solution and the greatest distance with the negative ideal solution. The higher the value of the index, the more favorable it will be. This method includes six steps.

The first step includes the formation of the fuzzy decision matrix (Equation 1). The columns of this matrix $\tilde{X}_{ij}$ are the criteria and its rows are the options. The elements of this matrix, i.e. $\tilde{X}_{ij}$, show the performance of the i-th option considering the *j*-th criterion. Triangular fuzzy numbers were used to transform expressions. Therefore, the decision-making matrix for the gypsum factory was formed according to the effective criteria (factors) and suitable options for establishing the relevant industry.

$$\tilde{D} = \begin{bmatrix} \widetilde{x_{11}} & \widetilde{x_{12}} & \cdots & \widetilde{x_{1n}} \\ \widetilde{x_{21}} & \widetilde{x_{22}} & \cdots & \widetilde{x_{2n}} \\ \vdots & \vdots & \cdots & \vdots \\ \widetilde{x_{m1}} & \widetilde{x_{m2}} & \cdots & \widetilde{x_{mn}} \end{bmatrix} \tag{1}$$

The second step is to normalize the fuzzy decision-making matrix that the elements of this matrix are represented by r_{ij}. If the elements of the fuzzy decision matrix are $x_{ij}= (a_y,b_y,c_y)$, then the relationship is established. In this step, the maximum value of each element of the matrix was determined and each of the elements was divided by its maximum value.

$$\begin{aligned} \widetilde{r_{ij}} &= \left(\frac{a_{ij}}{c_j^+}, \frac{b_{ij}}{c_j^+}, \frac{c_{ij}}{c_j^+}\right), \ j \in benefit, c_j^+ = max_i c_{ij} \\ \widetilde{r_{ij}} &= \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right), \ j \in cost, a_j^- = min_i a_{ij} \end{aligned} \tag{2}$$

In the third step, by multiplying the weights of different criteria in the normalized decision-making matrix, this matrix is weighted. The elements of this matrix (V) are denoted by v_{ij} (Equation 3). In this step, each of the second step matrix elements was multiplied by the AHP weight of each criterion.

$$\tilde{V} = [\widetilde{v_{ij}}], \qquad \widetilde{v_{ij}} = \widetilde{r_{ij}}(.)\widetilde{w_j} \tag{3}$$

In the fourth stage, the positive ideal was considered as (1,1,1) and the negative ideal as (0,0,0). In the fifth step, the distance of each option from the ideal positive (di^+) and ideal negative (di^-) points was calculated (Equations 4, 5, 6, and 7).

$$A^+ = \left(\widetilde{v_1}^+, \widetilde{v_2}^+, \dots, \widetilde{v_n}^+\right), \quad \tilde{v}_j^+ = (1,1,1) \tag{4}$$

$$A^- = \left(\widetilde{v_1}^-, \widetilde{v_2}^-, \dots, \widetilde{v_n}^-\right), \quad \tilde{v}_j^- = (0,0,0) \tag{5}$$

$$d_i^+ = \sum_{j=1}^{n} d(\widetilde{v_{ij}}, \tilde{v}_j^+), \ i = 1,2,\dots,m \tag{6}$$

$$d_i^- = \sum_{j=1}^{n} d(\widetilde{v_{ij}}, \tilde{v}_j^-), \ i = 1,2,\dots,m \tag{7}$$

Here, d shows the Euclidean distance, which is obtained for the two triangular fuzzy numbers $m=(a_1,b_1,c_1)$ and $n=(a_2,b_2,c_2)$ in the form of equation 8.

$$d(\tilde{m},\tilde{n}) = \sqrt{\frac{1}{3}[(m_1-n_1)^2 + (m_2-n_2)^2 + (m_3-n_3)^2]} \tag{8}$$

In the sixth step, the proximity coefficient of each option is calculated according to the positive and negative ideal points. Considering that the value of this numerical index is between zero and one, any option whose value is closer to one indicates the superiority of that option over other options (Equation 9) (Asgharpour, 2013).

$$CC_i = \frac{d_i^-}{d_i^+ + d_i^-} \quad (9)$$

Results

In this section, the results of processing satellite images such as false color composition and band ratio to check the access to raw materials of gypsum industry, the weighting of effective criteria in locating by AHP, superimposition of fuzzy standardized layers using the WLC method and the prioritization of suitable areas for the establishment of the industry are provided by the fuzzy TOPSIS method.

The maps of the effective criteria in locating the gypsum factory were standardized based on the limits presented in Table 3-3 on a scale of 0-255 and fuzzy functions in the IDRISI TerrSet environment. The final map of the weighted linear combination was obtained by superimposing the standardized maps using the fuzzy method. The results showed 4 suitable areas with an area of 57,102 hectares for the establishment of a gypsum factory in the Qom, Salafchagan, and Kahak sectors (Figure 5).

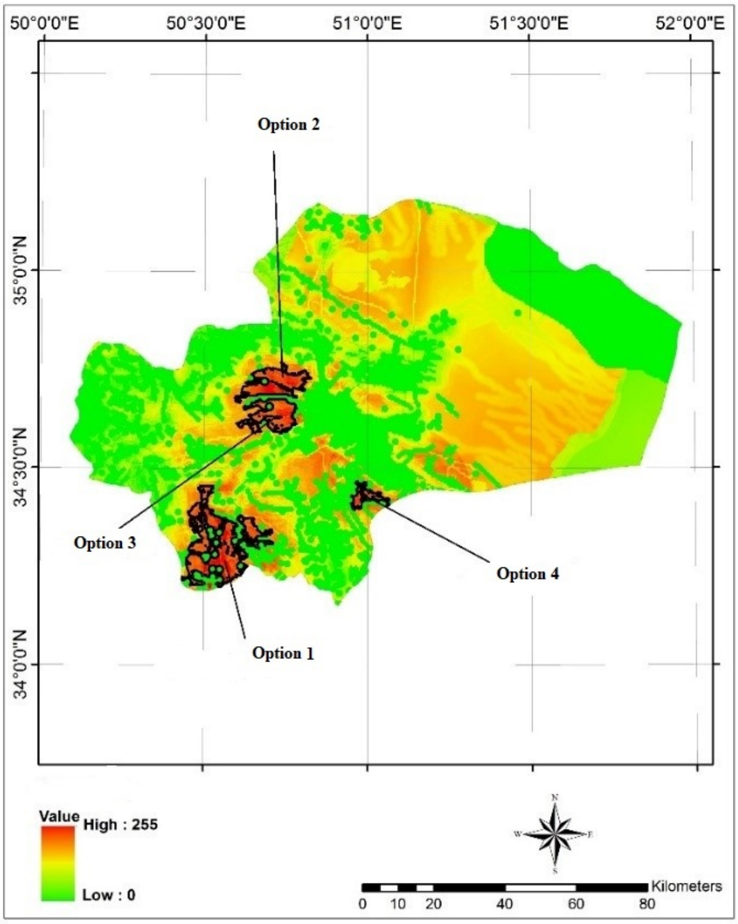

Figure 5. The final map from the overlay of layers using the weighted linear combination method for the establishment of a gypsum factory

The weighting of the effective criteria in the site selection of the gypsum industry was done using the AHP method. Based on the weighting results, the distance from gypsum mines with a weight coefficient of 0.231 was the most important criterion and the distance from industries with a weight coefficient of 0.021 was the least important criterion for the establishment of a gypsum factory. Also, the inconsistency coefficient of 0.07 was obtained for the gypsum factory, which indicates the consistency of the judgments (Table 4).

Table 4. The weight of the effective criteria in site selection of gypsum factory using the AHP method

Row	Criteria	Final weight
1	Distance from gypsum mine	0.231
2	Land use	0.094
3	Distance from the well and spring	0.060
4	Distance from residential areas and agricultural land	0.167
5	Groundwater depth	0.060
6	Distance from power transmission lines	0.093
7	Slope	0.108
8	Distance from communication routes	0.106
9	Distance from surface water	0.060
10	Distance from industries	0.021
	(C.R)	0.07

In this study, after determining four completely suitable sites with a large area by the WLC method for establishing a gypsum factory, the alternatives were prioritized by the fuzzy TOPSIS method.

First, a decision-making matrix was formed for the gypsum factory according to ten criteria and four alternatives. Then, the numbers of each class from the fuzzy map of each criterion were converted into triangular fuzzy numbers (Table 5).

Table 5. Decision matrix in the fuzzy TOPSIS method for gypsum factory

Criteria / Options	Distance from gypsum mine	Distance from surface water	Distance from the well and spring	Groundwater depth	Distance from residence	Land use	Slope	Distance from power transmission lines	Distance from the road	Distance from industries
Option1	9,10,10	9,10,10	9,10,10	0,0,1	0,0,1	9,10,10	9,10,10	9,10,10	9,10,10	0,1,3
Option2	5,7,9	9,10,10	9,10,10	0,0,1	0,0,1	1,3,5	9,10,10	9,10,10	9,10,10	0,0,1
Option3	9,10,10	9,10,10	9,10,10	0,0,1	0,0,1	1,3,5	0,0,1	9,10,10	3,5,7	0,1,3
Option4	7,9,10	9,10,10	9,10,10	0,1,3	0,0,1	9,10,10	0,0,1	9,10,10	3,5,7	0,0,1
Max	10	10	10	3	1	10	10	10	10	3

Then, for normalization, the maximum values of each of the members of this matrix (Table 5) were determined, and by dividing the values of each member by the maximum of this matrix member, the normalized fuzzy decision matrix was formed (Table 6).

Next, by multiplying the weights of different criteria obtained by the AHP method in the normalized decision matrix of fuzzy TOPSIS, the decision weighting matrix was obtained (Table 7).

The positive ideal was considered as (1,1,1) and the negative ideal was considered as (0,0,0). Then, to obtain the distance of each alternative from the positive and negative ideal points, the difference between the weighted matrix and the positive and negative ideal points was obtained

(Tables 8 and 9). The distance of alternatives from positive and negative ideal points was calculated according to Table 10.

Table 6. Normalized matrix of fuzzy decision making

Criteria / Options	Distance from gypsum mine	Distance from surface water	Distance from the well and spring	Groundwater depth	Distance from residence	Land use	Slope	Distance from power transmission lines	Distance from the road	Distance from industries
Option1	0.9,1,1	0.9,1,1	0.9,1,1	0.33,0,0	0,0,1	0.9,1,1	0.9,1,1	0.9,1,1	0.9,1,1	0,0.33,1
Option2	0.5,0.7,0.9	0.9,1,1	0.9,1,1	0.33,0,0	0,0,1	0.1,0.3,0.5	0.9,1,1	0.9,1,1	0.9,1,1	0,0,0.33
Option3	0.9,1,1	0.9,1,1	0.9,1,1	0.33,0,0	0,0,1	0.1,0.3,0.5	0.1,0,0	0.9,1,1	0.3,0.5,0.7	0,0.33,1
Option4	0.9,1,0.7	0.9,1,1	0.9,1,1	0.33,0,0	0,0,1	0.9,1,1	0.1,0,0	0.9,1,1	0.3,0.5,0.7	0,0,0.33
Criteria weight	0.231	0.031	0.040	0.039	0.147	0.074	0.088	0.071	0.086	0.021

Table 7. The weighting of the normalized fuzzy TOPSIS matrix

Criteria / Options	Distance from gypsum mine	Distance from surface water	Distance from the well and spring	Groundwater depth	Distance from residence	Land use	Slope	Distance from power transmission lines	Distance from the road	Distance from industries
Option1	0.20,0.23, 0.23	0.03,0.03, 0.03	0.03,0.04, 0.04	0,0,0.01	0,0,0.1	0.06,0.07, 0.07	0.07,0.08, 0.08	0.06,0.07, 0.07	0.07,0.08, 0.08	0.0.02, 0
Option2	0.11,0.16, 0.20	0.03,0.03, 0.03	0.03,0.04, 0.04	0,0,0.01	0,0,0.1	0, 0.02, 0.03	0.07,0.08, 0.08	0.06,0.07, 0.07	0.07,0.08, 0.08	0,0, 0.01
Option3	0.20,0.23, 0.23	0.03,0.03, 0.03	0.03,0.04, 0.04	0,0,0.01	0,0,0.1	0, 0.02, 0.03	0,0,0	0.06,0.07, 0.07	0.02,0.04, 0.06	0,0.02, 0
Option4	0.16,0.20, 0.23	0.03,0.03, 0.03	0.03,0.04, 0.04	0.03, 0, 0.01	0,0,0.1	0.06,0.07, 0.07	0,0,0	0.06,0.07, 0.07	0.02,0.04, 0.06	0,0, 0.01

Table 8. The difference matrix between the points of the normalized fuzzy TOPSIS decision matrix and the positive ideal solution

Criteria / Options	Distance from gypsum mine	Distance from surface water	Distance from the well and spring	Groundwater depth	Distance from residence	Land use	Slope	Distance from power transmission lines	Distance from the road	Distance from industries
Option1	0.7763	0.9618	0.9608	0.9951	0.9530	0.9280	0.9144	0.9309	0.9164	0.9902
Option2	0.8387	0.9618	0.9608	0.9951	0.9530	0.9773	0.9144	0.9309	0.9164	0.9971
Option3	0.7763	0.9618	0.9608	0.9951	0.9530	0.9773	0.9965	0.9309	0.9566	0.9902
Option4	0.7999	0.9618	0.9608	0/9823	0.9530	0.9280	0.9965	0.9309	0.9566	0.9971

Table 9. The difference matrix between the points of the normalized fuzzy TOPSIS decision matrix and the negative ideal solution

Criteria / Options	Distance from gypsum mine	Distance from surface water	Distance from the well and spring	Groundwater depth	Distance from residence	Land use	Slope	Distance from power transmission lines	Distance from the road	Distance from industries
Option1	0.2234	0.0377	0.0386	0.0075	0.0848	0.0715	0.0851	0.0686	0.0831	0.0127
Option2	0.1659	0.0377	0.0386	0.0075	0.0848	0.0252	0.0851	0.0686	0.0831	0.0040
Option3	0.2234	0.0377	0.0386	0.0075	0.0848	0.0252	0.0050	0.0686	0.0452	0.0127
Option4	0.2021	0.0377	0.0386	0.0237	0.0848	0.0715	0.0050	0.0686	0.0452	0.0040

Table 10. The distance of alternatives from ideal positive and ideal negative points

Options	Distance from the positive ideal	Distance from the negative ideal
Option1	9.3273	0.7135
Option2	9.4460	0.6010
Option3	9.4989	0.5492
Option4	9.4672	0.5817

In the last step, the proximity coefficient of each alternative was calculated and the alternative with a higher proximity coefficient was ranked higher (Table 11). As shown in table 11, alternative 1 has the highest priority because its proximity coefficient is higher than other alternatives and it has the smallest distance from the positive ideal and the largest distance from the negative ideal. alternatives 2, 4, and 3 are the next priorities, respectively.

Table 11. The degree of the relative proximity of each alternative to the negative and positive ideal solution and the prioritization of the alternatives

Options	Relative Proximity	Ranking Options
Option1	0.0710	1
Option2	0.0598	2
Option3	0.0546	4
Option4	0.0578	3

Discussion and Conclusion

This research has focused on locating suitable areas for the development of gypsum industries By using different criteria, weighting them by AHP, and superimposing fuzzy standardized layers using the WLC method. Then, prioritization of the suitable areas for the establishment of the industry was done by the Fuzzy TOPSIS method.

By studying previous researches and existing standards and effective criteria for site selection of the gypsum factory in Qom province, 12 criteria were used for locating the gypsum factory (Omidi, 2017; Reisi et al, 2018). The desired criteria include 3 categories of physical, environmental, and socio-economic criteria. The criteria include 10 factor criteria such as slope, distance from wells and springs, distance from surface water, depth of underground water, distance from power transmission lines (electricity and gas), distance from communication ways (railway and asphalt), distance from industries, land use, distance from residential areas and agricultural lands, and access to raw materials (gypsum). Two criteria of distance from fault and distance from protected areas were considered as constraint criteria. Also, due to the adverse effects that gypsum dust has on agricultural products and people's health, the criteria of distance from the residential areas and agricultural lands are used as both constraint and factor criteria.

Some studies have been done in the field of site selection of industries (Omidi et al, 2022; Reisi et al, 2018). But site selection of industries by industry type has rarely been discussed. One of the most important debates that is discussed in the site selection of industries by their types is the access to raw materials required by the industries. Access to raw materials for the establishment of factories such as gypsum, which deal with a huge amount of minerals, is the most important criterion because transportation costs account for a significant percentage of the total costs. Since the raw materials of this industry and their final product are not expensive, the proximity of these industries to the mines of their raw materials is very important. On the other hand, it is not cost-effective to transport raw materials and their products over long distances.

In this study, remote sensing capability was used to prepare the standard information layer of access to raw materials. In recent years, remote sensing has been a powerful tool in the regional exploration of deposits. In this research, the promising areas of clay mineralization (gypsum and calcite minerals) were investigated using Landsat OLI image processing. Landsat OLI satellite images provide effective spectral and reflectance information of the studied area. The investigated area located in Qom province was studied in terms of the presence of clay mineral mineralization areas with selective principal component analysis methods (Crosta) and ratios related to the desired mineralization, that the information about suitable spectral bands for the mineralization of clay minerals has been extracted from reference spectral libraries. In the method of band ratios, by using the bands that give the most reflection and absorption concerning the desired mineralization, the areas related to the mineralization of clay minerals were determined on the map. Also, in the Crosta method, the appropriate components for identifying the mineralization of clay minerals in the region were investigated and the promising areas of clay mineralization were determined on the map. Therefore, these images can be used as exploratory guides in field studies to explore areas with the mineralization potential of clay minerals and, as mentioned, avoid wasting time and cost in exploratory activities.

After superposing all the maps, the wind direction criterion was also considered. The condition of wind direction is another important criterion in the development of industries, and air pollution management, and as a result, the site selection of the gypsum factory, which was not involved in the combination of layers at first due to its vector characteristics. Such factories should not be located in the direction of the prevailing wind towards residential areas and other industries due to the release of dust during the production process. According to the windrose of Qom province, it was found that the prevailing wind blows from the west to the east of the province. Also according to windrose, the prevailing wind in the cities of Kahak and Salafchegan is from the northeast to the southwest. Therefore, factories should not be built in the western and northeastern parts of these sectors. In other words, the prevailing wind from the proposed locations is not towards residential areas and other industrial units, and these areas are not affected by the pollution from these factories. The proposed sites for the gypsum factory in the cities of Salafchegan, Qom, and Kahak are suitable because they are not located in the direction of the prevailing wind. Anyway, by taking into consideration remediation methods such as creating a green belt and planting suitable trees to absorb suspended particles caused by gypsum industries, it is possible to reduce the adverse effects in receptors such as residential areas and agricultural lands.

According to the results of weighting using AHP, after determining and evaluating the weight of the desired criteria by experts, it was determined that for the site selection of the gypsum factory, the criteria of access to raw materials, and distance from residential areas and agricultural lands are more important, and the criteria of distance from Industries and distance from surface water are respectively less important than other criteria. The high importance of the criterion of proximity to mines is due to the reduction of costs caused by the transportation of raw materials to the factory site, and the high importance of the criterion of the distance from residential areas and agricultural lands is also due to the pollution caused by the dust of the gypsum factory on the health and agricultural products.

In this research, the final map was obtained by superimposing the standardized layers through fuzzy logic using the WLC method including 11 factor layers (two layers were also included as a constraint). Based on the final map 526 spots were identified with a value of 190 to 255 for the establishment of a gypsum factory in the class with very high suitability, and due to the small size of many spots, after applying the minimum area of 200 hectares, 24 spots have a high suitability with an area from 203 hectares to 23886 hectares with a total of 57102 hectares. 4 areas were identified in the southern parts of Qom, Kahak, and Salafchegan. In general, wherever gypsum mines are scattered, suitable sites are also there. In the northern part of Qom city, because there is no gypsum mine, there is no suitable site for a gypsum factory. In the fuzzy method, due to having a wide range of suitability (0 to 255), there is a higher decision-making power than the Boolean logic, which results from the study of Oveisi and Afzali, (2020) too. The results of this research showed that fuzzy logic has high flexibility compared to the Boolean method and is very effective in determining spatial evaluation with several criteria.

In this research, the Fuzzy TOPSIS method was used to prioritize the options. After ranking the 4 suitable options for the gypsum factory (Figure 4), option 1 with an area of 23886 hectares in Salafchagan was recognized as the best option.

The methods used in this study can also be used to locate other mining industries, although the number and limits of criteria should be adjusted according to the type of industry and the study area. Suggesting suitable areas for the establishment of industries can provide decision makers with possible options to make decisions under the political, financial, and executive conditions regarding the selection of the final option and avoid the complications of the improper establishment of the respective industries.

References

Afzali, A., Sabri, S., Rashid, M., Samani, J., and Ludin, A. (2014). Inter-municipal landfill site selection using analytic network process. Water Resources Management 28, 2179–2194.

Akbarzadeh, A., Gorji, M., Refahi, H.G., and Rouhipour, H. (2010). Assessment the effect of gypsum on temporary soil stabilization. natural environment Journal (natural resources of Iran), 2, 127-140.

Aronoff, S. (1989). Geoghraphic Information System. A Management Perspective, WDL Publication Ottawa.

Asgari, J., Alimohammadi, A., and Nasiri, Y. (2014). Application of remote sensing (RS) in mineral exploration. National conference on the application of Models of Advanced Space Analysis (Remote Sensing and GIS) in the land, 24th February, Yazd, Iran.

Asgharpour, M.J. (2013). Multi criteria decision makings. Tehran: University of Tehran Press.

Ataei, M. (2005). Selecting Alumina- cement plant locating by TOPSIS approach. Amirkabir journal, 62, 77-83.

Atthirwang, W., and MacCarthy, B. (2002). An application of analytical hierarchy process to international location decision making. 7th Cambridge Research Symposium on International Manufacturing. Centre for International Manufacturing, Cambridge University.

Chabra, A., Samuel, C.H., and Annadurai, R. (2015). GIS Based Multi-Criteria Analysis for Cement Plant Site Selection for Cuddalore District. 36th Asian Conference on Remote Sensing, Manila, Philippines.

Chu, M.T., Shyu, J., Tzeng G.H., and Khosla, R. (2007). Comparison among three analytical methods for knowledge communities group-decision analysis. Expert Systems with Applications Journal, 33, 1011-1024.

Deng, H. (1999). Multicriteria analysis with fuzzy pairwise comparison. International Journal of Approximate Reasoning, 21, 215-231.

Gabr, S., Ghulam, A., and Kusky,T. (2010). Detecting areas of high-potential gold mineralization using ASTER data. Ore Geology Reviews, 38, 59-69.

Ghodsipour, H. (2002). Analytical Hierarchy Process (AHP). Tehran: Amirkabir University.

Gupta, R.P. (2003). Remote Sensing Geology. Second edition, Verlag, Berline: Springer.

Guzman, L. (2015). Localization factors from Japanese firms in automotive-related industries in Mexico. Procedia Economics and Finance, 30, 265-70.

Hadad, A., Naeimi, M., and Zolfagharian, I. (2015). Evaluation of the environmental effects of mines and gypsum processing factories in Momenabad, Semnan, using the ICOLD matrix method. International Conference on Environmental Sciences, Technology and Engineering, 5th May, Tehran, Iran.

Jafari, D., and Kalantari, S. (2014). Locating a cement factory with a fuzzy approach. 7th August The first international management conference in the 21st century, Tehran, Iran.

Khaliji, M.A. and Saeedeh Zarabadi, Z.S. (2015). An analysis on industrial towns site selection in Tabriz city using multi-criteria decision making models. Journal of Regional Planning, 19, 101-114.

Linkov, I., Satterstorm, F.K., Kiker, G., Seager, T.P., Bridges, T., Gardner, K.H., et al. (2006). Multicriteria decision analysis: A compehensive decision approach for management of contaminated sediments. Risk analysis Journal, 26, 61-78.

Madadi, A., Azadi mobaraki, M., and Babaei aghdam, F. (2013). Modeling suitable landfill sites using AHP methods, fuzzy logic, weighted overlap index and Boolean logic (case study of Ardabil city). Qurterly of Geography and Regional Planning, 45, 235-254.

Omidi, K. (2017). Locating industries using multi-criteria decision analysis in GIS environment in Kashan city. Master's thesis, University of Kashan.

Omidi, K., Afzali, A., Vahidi, H., and Mahnam S. (2022). Ranking of Suitable Areas for Establishing Industries in Kashan City Using VIKOR and TOPSIS Methods in Fuzzy Environment. Journal of Advances in Environmental Health Research, 10(2), 133-148.

Opricovic, S., and Tzeng, G.H. (2004). Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. European Journal of Operational Research, 156, 445-55.

Oveisi, S., and Afzali, A. (2020). Selecting municipal solid waste landfill site in Kashan City using OWA and TOPSIS fuzzy methods (Persian)].Desert Ecosystem Eng J, 9(27), 79-92.

Parhizkar, A., and Ghafari Gilandeh, A. (2006). GIS and Multicriteria Decision Analysis. Tehran: Samt publication.

Rahmani, N., Ranjbar, H., Sam, A. and Taghinejad, A., (2014). Locating the construction site of the mineral processing plant using hierarchical analysis method (Case study: Chah Firuzeh cupper mine). 10th International Industrial Engineering Conference, 27th January, Tehran, Iran.

Ravix, J. (2014). Localization, innovation and entrepreneurship: an appraisal of the analytical impact of marshall's notion of industrial atmosphere. Journal of Innovation Economics and Management, 2, 63-81.

Razavi, M.M., Kazemi Biniaz, M., Asadi, A., and Ajaaz shokohi, M. (2015). Evaluation of urban green space and locating it using fuzzy multi criteria desition making (Case studt of 3rd municipality region of Mashhad). Geographic Space Journal, 15, 1-17.

Reisi, M., and Soffianian, A. (2010). Locating industries using geographic criteria (Case study: fifty kilometers radius of Isfahan city). Geographical Research Journal, 99, 115-134.

Reisi, M., Afzali, A., and Aye, L. (2018). Applications of analytical hierarchy process (AHP) and analytical network process (ANP) for industrial site selections in Isfahan, Iran. Environmental Earth Sciences, 537, 1-13.

Sabins, F. (1999). Remote sensing for mineral exploration. Ore Geology Reviews, 14, 157-183.

Shafaei, A.H., Rabani, Y., and Hashemiyan, N. (2013). Assessing of site selection effective parameters based on sustainable development principles using fuzzy delphi analytical hierarchy process (FDAHP) (Persian). The 8th Symposium on Advances in Science and Technology, 18 December; Mashhad, Iran.

Tiwari, P. (2014). General factors influencing location of industries in India. available in: http://www.geographynotes.com/industries/7-general-factors-influencing-location-of-industries-in-india.1054. 2014.

Torabi, H. (2011). Locating gypsum and cement industries using fuzzy, AHP and FAHP methods in Isfahan province. Master's thesis, Shahid Bahonar University of Kerman.