Centre for Research on Settlements and Urbanism

Journal of Settlements and Spatial Planning

Journal homepage: http://jssp.reviste.ubbcluj.ro

Application of Delphi-AHP and Fuzzy-GIS Approaches for Site Selection of Large Extractive Industrial Units in Iran

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K e y w o r d s: *GIS, AHP, Delphi method, large extractive industrial units*

A B S T R A C T

This research was conducted to identify and prioritize the key performance criteria and sub-criteria involving in the site selection of the large extractive industrial units (100,000 t/year) as one of the first steps to prevent the adverse environmental effects of such industrial activities. Along with this purpose, effective environmental (ecologic, economic and social) criteria which may have a significant role in site suitability assessments have been determined using Delphi method. After screening the identified criteria, pair comparisons were carried out among the criteria and sub-criteria, respectively, based on the analytical hierarchy process. Consequently, the priority of each criterion and sub-criterion was determined regarding the purpose of the study. As a result, a linear relationship (defined as ax + b) was identified; based on the criteria normalized relative weights. The results showed that among the identified criteria, the distance to raw material mines would be the most important criterion whereas social variables have received the least importance among the investigated criteria. Then, the results of AHP method were utilized to perform a weighted linear combination in GIS in order to make a prioritization of the suitable sites for establishing a large extractive industrial unit in Iran, as the case study. The obtained results showed a high efficiency of the combination of Delphi-AHP with fuzzy-GIS for prioritization and ranking the influencing criteria and identifying the suitable sites in such applications.

1. INTRODUCTION

Finding suitable sites for the large extractive industrial units (LEIU), as for all kinds of services and manufacturing activities, is a very important and necessary step to ensure the success and long-term sustainability of production. Site selection, as a decision support tool, can significantly improve the production quality and increase the satisfaction of the stakeholders [1].

This process, in particular for such high-polluting industries, involves not only primary criteria, such as good visibility and access, but also more complex criteria, in terms of their long-term environmental subsequent effects, such as access to raw materials and labour, as well as water and energy resources [2]. No doubt that dealing with such disaggregated data by traditional means requires considerable time and sometimes may not yield the desired results [3]. Thus, the evaluation of confusing tangible and intangible influencing criteria necessitates a multiple criteria decision analysis framework (MCDA), when deciding where to locate such industries [4]. MCDA methods can generally help assessing the strengths and weaknesses of various alternatives, mostly based on the concepts of accurate measurements and crisp evaluation [2], [5]. Such a site selection model includes a set of activities namely problem definition and structuring, screening and suitability evaluation of the criteria and sub-criteria, weighting the criteria and sub-criteria, and finally ordering the alternatives using an integration model (Fig. 1).

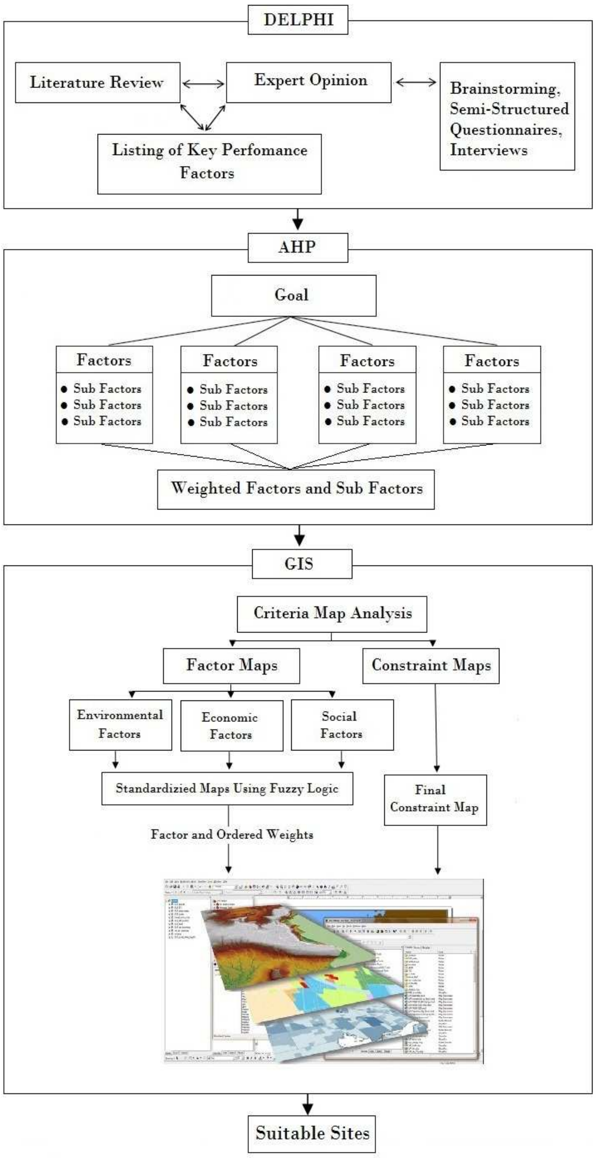

Fig. 1. Application stages of Delphi, AHP and GIS in a typical site selection process [3], [11], [12].

Delphi, firstly developed by Dalkey and Helmer (1963), is considered as an appropriate tool for screening the criteria through analyzing the personal opinion of experts. Using this method, a reliable consensus about the influencing criteria can be obtained by calculating the percentage of importance (PI) (Eq. 1) and the degree of importance (DI) (Eq. 4), with respect to the final goal of the study [6].

Delphi includes some advantages over others, such as the avoidance of a direct confrontation between the participant experts, and giving experts the opportunity to improve their own opinion by receiving the feedback reports [7].

The weighting process of the criteria includes some activities such as the determination of individual preferences, the combination of the individual judgments into a single collective preference, and the consistency analysis with respect to the set of evaluation criteria and alternatives [8]. There are many weight calculation procedures, but the analytic hierarchy process (AHP) has some benefits over others. One of the most important advantages of the AHP is to be based on pairwise comparison [2]. Furthermore, this method considers both qualitative and quantitative data and combines them by decomposing ill-structured problems into systematic hierarchies [9].

Besides, the AHP includes the inconsistency analysis (IA) which is the ratio of the decision-maker's inconsistency. In site selection applications, AHP provides a systematic tool for decision-makers in selecting the best alternative that can be integrated with other capable tools such as geographic information system (GIS), which can incorporate efficient storage, management, and analysis of spatial and non-spatial data, and fuzzy methods to tackle uncertainties in the data [10].

So far, a number of studies have applied the Delphi, and AHP, and the integration of these methods with novel analytical models by using geographic information system in order to select the appropriate sites for various applications such as energy production facilities [13], aquaculture applications [14], landfill site selection [15]. Moreover, some studies have utilized such combinations for establishing the industrial activities. For instance, Rikalovic, Cosic, & Lazarevic (2014) presented a multi-criteria spatial analysis for industrial site selection in the Vojvodina, as an interesting region for industrial activities [16].

However, there are a limited number of the published papers on the site selection of the strategic large-scale industries. In this paper, we aimed to use the DM and AHP techniques to identify the effective criteria and sub-criteria for the selection of the suitable sites for the large extractive industrial units, and weight the selected criteria. Afterwards, a fuzzy-GIS procedure was applied to identify the most promising areas to locate a large extractive industrial unit in Iran.

2. METHODS AND MATERIALS

2.1. Criteria and sub-criteria screening by DM

Delphi can be used as a mathematical method to assess and summarize the experts' opinions through PI and DI analysis. The PI mathematical equation is given in Eq. (1) [17].

$$PI = \frac{(\Sigma Z_i)}{A} \times 100 \quad (1)$$

where: "A" is the maximum obtainable weighted value (Eq. 2). In this equation, "N" is the total number of experts who participated, and "Z_i" refers to the weighted value of each criterion, which can be calculated through Eq. (3).

$$A = N \times 10 \quad (2)$$

$$Z_i = Y_i \times n \quad (3)$$

In this equation, "Y_i" describes the moderated values of the criteria which can be achieved by multiplying the initial values of the criteria by moderated coefficient (Eq. 4). Also, "n" is the given number of the experts involved in the evaluation of importance of each criterion, in which case they gave their opinion about each of criteria in the form of degrees as 1, 3, 5, 7 and 9 importance values.

$$X_i = \frac{10}{(\Sigma(1+3+5+7+9))} \quad (4)$$

Finally, DI can be calculated by Eq. (5) as follows:

$$DI = \frac{(X_i \times n)}{N} \quad (5)$$

DI and PI were used to draw a 2D graph based on Delphi method called importance graph (IG). In this regard, only those criteria are acceptable that get PIs or DIs larger than the median value of both axes of the IG. In this study, the Delphi questionnaires were prepared regarding the main goal of the study, including three main criteria and thirteen sub-criteria, identified through reviewing the related scientific literature ([18]–[26]), considering the specific requirements of the LEIU listed in Table 1.

Besides the mentioned criteria and sub-criteria, there are some environmental limitations for establishment of the industrial and manufacturing units and activities, which must be taken into account during the selection of suitable sites for such activities. For instance, the Iranian legislation on the establishment of large extractive industrial units is given in Table 2.

Afterwards, 10 participant experts with acceptable competency in the environmental science and engineering field, having enough knowledge on the technical aspects of such industrial activities, were selected from the public and academic community and asked to give their own values for each criterion based on the DM procedure as well as for pairwise comparisons involving in the AHP method (2.2). This way, the PIs and DIs, as well as the ranking the criteria and sub-criteria, were calculated forming the final results of the study.

Table 1. Identified criteria and sub-criteria, in addition to the acceptable range for each criterion.

Criteria	Sub-Criteria	Acceptable range
Ecologic criteria	Height	$0\ m \leq C \leq 1800\ m$
	Slope	$0° \leq C \leq 30°$
	Geology	Based on the relative strengths of the local rocks
	Soil properties	Based on the relative sensitivity of the soil to erosion and salinity
	Distance from the faults	$C > 1000\ m$
	Existing land use pattern	According to the relative importance of the existing land use patterns
Economic criteria	Transportation	As the distance to the main access roads ($C \geq 0$ m)
	Raw materials supply	As the distance to raw material mines ($C \geq 0$ m)
	Water supply	As the distance to local deep and semi-deep water wells, except of agricultural water wells ($C \geq 0$ m)
	Power supply	As the distance to local power transmission lines ($C \geq 0$ m)
	Gas supply	Based on the distance to local gas pipelines ($C \geq 300$ m)
Social criteria	Local labor	Based on the availability of the local labor
	Education level	As a development marker, describable as the number of educated people per unit area

Table 2. Legal requirements for LEIU site selection in Iran [27].

No.	Minimum distance to sensitive areas
1	2500 m away from the province capitals
2	2000 m away from the county seats
3	2000 m away from other towns
4	1500 m away from villages
5	1500 m away from health and education centres
6	1500 m away from military centres
7	2000 m away from national park, lake, wetland and national natural monument
8	1000 m away from wildlife sanctuary and protected area
9	500 m away from non-drinking permanent river
10	2000 m away from drinking permanent rivers
11	500 m away from agricultural water wells

2.2. AHP for weighting the criteria and sub-criteria

AHP has mostly been applied to make the beneficial decisions in operational and risk analysis for evaluation of the project alternatives as well as in evaluation of the environmental consequences [18] mainly due to:

- providing a detailed, structured and systematic decomposition of the overall problem into its fundamental components and interdependencies;

- having a large degree of flexibility;

- having the ability to handle both tangible and intangible attributes and characteristics;
- providing a mechanism to monitor the consistency with which a decision-maker makes a judgment;
- having the capability to be used in combination with many other approaches (fuzzy set theory, optimization, etc.).

This method, which has been firstly used in site selection problems by Siddiqui et al. (1996), allows the decision-makers to solve complex problems by forming a hierarchical structure and evaluating a number of qualitative and quantitative criteria in a systematic manner [19].

AHP, as a well-known tool, has been widely used, independently or in combination with other methods, for ranking the alternatives and choosing the best choice, when a decision-maker is facing with various criteria [15], [22], [28], [29]. The procedure of this method has been designed based on three main principles [30], [31]:

- organizing the problem into a hierarchy structure;
- applying the pairwise comparisons among the criteria and sub-criteria;
- calculating the weights of the influencing criteria.

The first step is used to decompose the main problem into a hierarchical structure (Fig. 2).

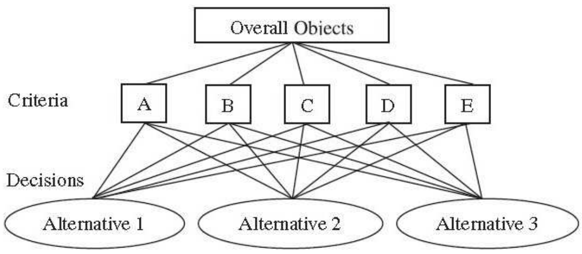

Fig. 2. A schematic structure of the AHP [32].

The head of this tree (the first level) shows the goal (problem). The second level consists of the criteria and sub-criteria, and at the lowest level, the choices would be placed.

Then, the relative weights of the elements in the hierarchical levels would be determined in referring to others, through composing a pairwise comparison decision matrix (Eq. 6).

$$A = [a_{im}] = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \cdots & 1 \end{bmatrix} i, m = 1, 2, \ldots, n. \quad (6)$$

The calculation of the relative weights is performed by normalization of the decision matrix. For this, each set of column values is computed and each value is divided by its respective column total value. Finally, the average of row values is calculated and the weights of the decision-maker's objectives are obtained [33].

The ratio scale between 1-9 was used for pairwise comparisons [12], [18]. The score of 1 indicates that the two components have equal importance, whereas a score of 9 indicates the overwhelming dominance of the considered component over the comparison component. If the effect of one component is weaker than that of its comparison component, it will be scored from 1 to 1/9, which 1 indicates indifference and 1/9 reflects the overwhelming dominance of the column component over the row component [34].

Checking out the consistency of each matrix consistency is the next step, which is calculated as the consistency ratio (CR) (Eq. 7) to ensure that the judgments of decision-makers are consistent.

$$CR = \frac{CI}{RI} \quad (7)$$

In this equation, "RI" is the random index obtained from a table established by Saaty (1980), for matrix with rows going from 1 to 15. "CI" is the consistency index, which is determined by using the Eq. (8) [28]:

$$CI = \frac{\lambda \max \quad n}{n \quad 1} \quad (8)$$

Where "$\lambda_{\max}$" is the highest eigenvalue of the pairwise comparison and "n" is the criteria number. If "CR" is less than 0.1, then the priorities assigned are considered satisfying, and the derived weights can be used. Otherwise, for the numbers higher than 0.1, the judgments have been made by decision-makers are not consistent to generate weights and they are subject to be revised and improved.

2.3. Fuzzy Logic and GIS

So far, various methods such as Boolean, overlay index (OI) and fuzzy logic were utilized in order to integrate the criteria and sub-criteria to resolve the existing decision making problems [35]–[37]. However, fuzzy logic has been shown to have some inherent benefits over other methods [38]. It is evident that in the fuzzy logic, the certainty of Boolean logic does not exist, and, therefore, the values of each individual information layers are ranked on a scale between 0 and 1. In this study, after the preparation of the information layers related to the study area, Nezam Abad Tungsten mine (Iran) (Fig. 3), the fuzzy logic was applied in order to find the suitable sites for establishing a large tungsten extraction industrial unit.

To this end, the information layers were preliminarily prepared according to the linear fuzzy and J-shaped fuzzy functions [39], [40], and the weighted linear combination method (WLC) (Eq. (9)) was applied (see e.g. [41]) using ArcGIS 9.3 software.

$$S = \sum_{i=1}^{n} w_i x_i \tag{10}$$

Here, n is the number of the sub-criteria, W_i is the weight of the criterion (x_i), achieved based on the AHP method (see 2.2).

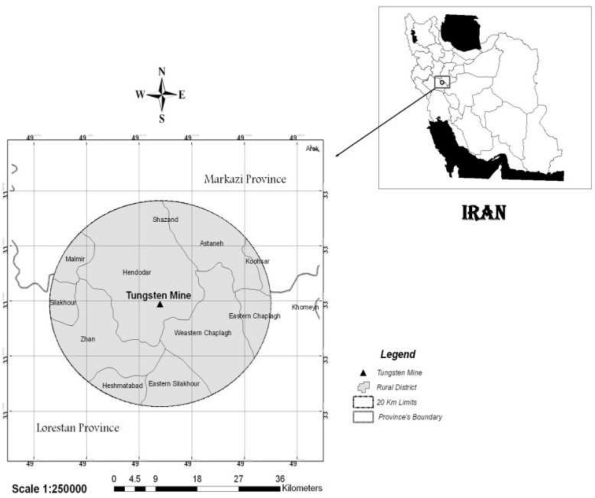

Fig. 3. Study area (Nezam Abad Tungsten mine, Markazi Province, Iran).

3. RESULTS AND DISCUSSION

In terms of criteria suitability, the results of the Delphi analysis revealed that all values of PI and DI are higher than the median of the axes of IG (Fig. 4). Consequently, they can be considered as suitable criteria regarding the main goal of the study. Moreover, it can be realized from Fig. 5 that *"raw materials supply"* and *"power supply"* have gotten the most values of DI and PI, while *"height"*, *"geology"* and *"local labour"* are considered less important than other selected criteria.

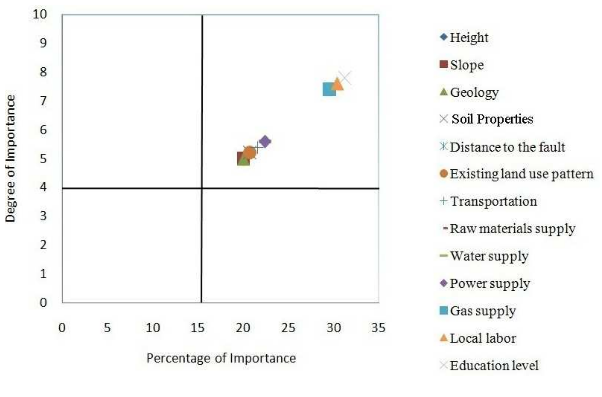

Fig. 4. Importance graph of proposed criteria.

The results of this study indicated the capability of DM to deal with complicated problems such as environmental issues, as stated by Turoff and Linstone (2002) [42], including site selection applications dealing with different types of qualitative and quantitative criteria revealed by Hasanzadeh et al. (2012) [17], mainly because of simultaneously analysis of the data and the results [6].

Table 3 shows the mathematical calculations of Delphi method. Afterwards, the participant experts were given a criteria and sub-criteria questionnaire based on the basic scale of pairwise comparison in order to identify the relative weights of the identified criteria and sub-criteria, based on AHP approach.

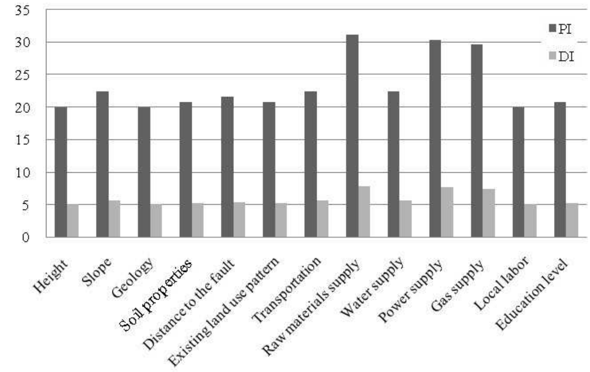

Fig. 5. Comparison of the sub-criteria regarding the percentage of importance and degree of importance.

Table 3. Sub-criteria PIs and DIs, achieved through the Delphi method.

Criteria	Sub Criteria	Percentage of importance	Degree of percentage
Ecologic criteria	Height	20	5.0
	Slope	22.4	5.6
	Geology	20	5.0
	Soil properties	20.8	5.2
	Distance to the fault	21.6	5.4
	Existing land use pattern	20.8	5.2
Economic criteria	Transportation	22.4	5.6
	Raw materials supply	31.2	7.8
	Water supply	22.4	5.6
	Power supply	30.4	7.6
	Gas supply	29.6	7.4
Social criteria	Local labor	20	5.0
	Education level	20.8	5.2

Analysis of the hierarchical tree, using Expert Choice 11 illustrated the acceptable overall inconsistency (0.03) (Fig. 6), as well as that for each expert's opinion, before combining the individual results. The combination results of the pairwise comparisons carried out by the participant experts are shown in Fig. 6.

As shown in Fig. 6 (left), *"Economic criteria"* have gotten the most final weight (49.4%) and *"Ecologic criteria"* and *"Social criteria"* have gotten the next priorities by 28.8% and 21.8%, respectively. This reflects the importance of increasing the profitability of the manufacturing activities especially by decreasing the cost of *"Raw material supply"*, achievable by minimizing the distance to the raw material mines which has gotten 15.93% of relative weight among the screened sub-criteria. Moreover, economic advantages of the industrial activities are directly related to the energy supply and relevant overall costs. So, these criteria have received noticeable relative weights by 11.96% and 11.58% for *"Gas"* and *"Power supply"*, respectively. Finally, *Transportation* (the distance to the main access roads (C ≥ 0 m)) and *Water supply*; described as the distance to the deep and semi-deep water wells (C ≥ 0 m) have gotten the next priorities with 9.97% and 3.58%, respectively.

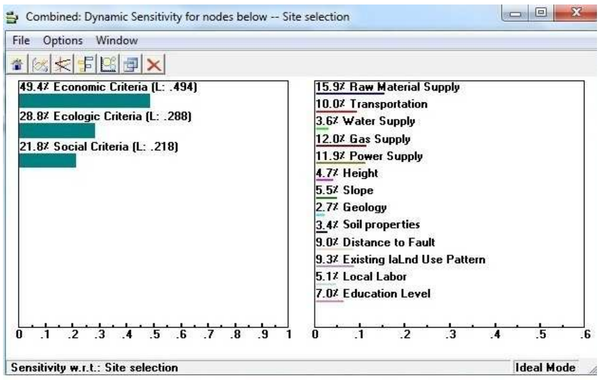

Fig. 6. Results of the pairwise analysis combination, achieved by Expert Choice 11.

In terms of ecologic criteria, as shown in Table 3, *"Existing land use pattern"* and *"Distance to the fault"* hold the highest share of relative values (09.27% and 09.05% respectively); while *"Geology"* and *"Soil properties"* have the least final relative weights among the ecological, and the all criteria. This shows that we must be very attentive to the high potential risk of the environmental pollution released by different manufacturing processes, especially for such high polluting industries, which can affect the environment, including the habitat areas. Moreover, it is very important to prevent the negative effects on the local ecosystems, as well as short-term or even long-term secondary effects on the local community walk of life.

In terms of social variables, *"Education level"*, as a Human Development Index (HDI) and a potential source of local experts for industrial activities, has gotten 07.01% of the relative importance compared with the *"Local labor"* which has been ranked the next place with 05.12% of the relative weight. These criteria have received the least importance among the investigated criteria with respect to the main goal of the study. The results arising from the application of the AHP (Fig. 7 and Table 4) revealed that social criteria do not play a significant role in the site selection of such industrial activities. Thus, decision-makers must be more attentive in considering the economic and ecological criteria, in order to increase the profitability and reduce the possible environmental risks might be included in such manufacturing activities.

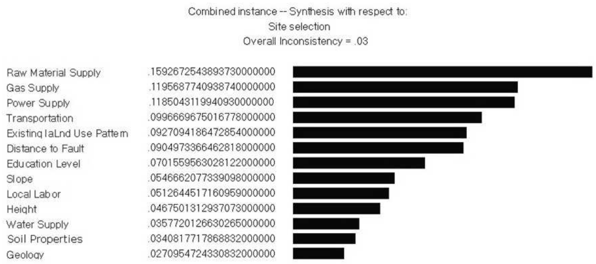

Fig. 7. Prioritization of the sub-criteria by Expert Choice 11.

Table 4. Final relative weights of the screened sub-criteria.

Priority	Sub criteria	Final weight (%)
1	Raw materials supply	15.93
2	Gas supply	11.96
3	Power supply	11.85
4	Transportation	09.97
5	Existing land use pattern	09.27
6	Distance to the fault	09.05
7	Education level	07.01
8	Local labor	05.12
10	Slope	05.47
9	Height	04.67
11	Water supply	03.58
12	Soil properties	03.41
13	Geology	02.71

Like other studies including the application of AHP to solve complicated problems, especially for site selection studies (see e.g., [6], [43]–[47]), the results achieved from the present study showed the reliability of the AHP which combines the experts' opinions with an acceptable degree of consistency. Hence, we can propose this method stated by Hasanzadeh, M., Danehkar, A., Azizi, M. (2013) as one of the most appropriate ways dealing with such environmental studies [6]. The linear relationship between the sub-criteria, based on their normalized values, arising through the application of AHP has been presented in (Eq. 9), considering the relevant descriptions of each criterion (2.1).

$$ES = [- (0.159\ EM) - (0.120\ GS) - (0.119\ PS) - (0.100\ TR) + (0.091\ DF^{a}) +/- (0.093\ LU^{d}) + (0.070\ EL) + (0.051\ LI) - (0.047\ H^{b}) - (0.055\ SL^{c}) + (0.036\ WS) +/- (0.034\ SP^{d}) +/- (0.027\ GE^{d})] \quad (9)$$

[a] DF>1000 m
[b] $0\ m \leq H \leq 1800\ m$
[c] $0° \leq SL \leq 30°$
[d] qualitative criteria

ES refers to LEIU site selection preference identified for a certain location, EM, 'raw materials supply', GS, 'gas supply', PS, 'power supply, TR, 'transportation, DF, 'distance to fault', LU, 'existing land use pattern', EL, 'education level', LL, 'local labour', H, 'height', SL, 'slope', WS, 'water supply', SP, 'Soil properties' and GE to 'geology'. Such relationships can aim decision-makers to understand the importance and priority of the criteria in similar studies. In this study, this equation was used to analyse the information layers which were prepared according to the fuzzy logic fundamentals. The result of the application of the WLC to integrate the information layers in GIS is shown in Figure 8. In this regard, the suitability of each individual site to establish a Tungsten extraction industrial unit in Markazi Province, Iran has been determined, based on its value calculated between 0, and 1, according to the fuzzy logic fundamentals.

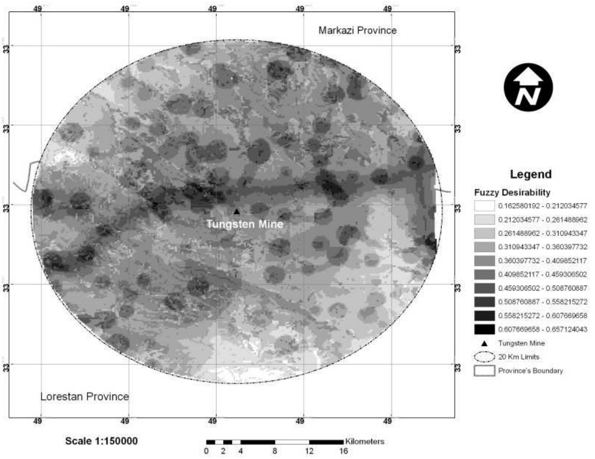

Fig. 8. Weighted linear combination of the sub-criteria for prioritization of the suitable sites for Tungsten extraction industrial unit in Iran.

From Figure 8 it can be concluded that a high level of reliability can be expected when AHP and fuzzy approaches in GIS are combined to solve the site selection problems for industrial applications. So far, the combination of the AHP and fuzzy-GIS has been utilized in some studies to select the suitable sites for various applications such as municipal solid waste management (e.g., [48]), selecting the shopping center sites (e.g., [2]), etc. However there are a limited number of the published papers on the application of such combinations for industrial site selection, especially for large industrial units. The results of the present study showed the high degree of the applicability of Delphi-AHP-fuzzy integration in GIS for such applications.

4. CONCLUSION

This manuscript presented an application of the MCDA for screening and prioritization of the criteria and sub-criteria influencing in the LEIU site selection. This approach includes a Delphi/ AHP aggregation procedure which can be used to generate the reliable decision alternatives to solve the site selection problems. Delphi methodology was used in this study to evaluate the appropriateness of the criteria, identified by reviewing the related scientific literature. The importance graph, which was drawn by calculating the PIs and Dis values, indicated that all of the proposed criteria are acceptable regarding the main goal of the study. To achieve the next objective, which was to prioritize the criteria and sub-criteria resulted from Delphi analysis, AHP methodology was employed through expert opinions analysis by Expert Choice 11. The results demonstrated that the distance to raw material mines, plays very important role in the success of a LEIU. Moreover, social criteria (including education level and potential source of local experts for industrial activities) are not considered as very significant criteria in this regard, determining the decision-makers to be more attentive when considering the economic and ecological criteria in order to increase the profitability and reduce the possible environmental risks. The results of the AHP were concluded in a linear combination between the selected sub-criteria, which was then integrated with a weighted linear combination to rank the suitable sites for establishing a Tungsten extraction industrial unit in Markazi Province, Iran, as the case study. In conclusion, the results of this study clearly indicated the potential and effectiveness of Delphi and AHP integration with fuzzy-GIS in order to support the complexity of decision-making in such industrial applications.

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