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**Technical Note**

# Selection of chromite processing plant site using fuzzy analytic hierarchy process (FAHP)

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**Abstract**

Based on existence of the chromite deposits in the Sistan and Baluchestan province in Iran, and also various applications of chromite in different industries, it is expected that the establishment of chromite processing plant is required in the erelong. The geographical location of a processing plant can have a strong influence on the success of an industrial venture. The processing plant site selection is a multi-criteria decision problem. The conventional methods used for a plant location selection are inadequate for dealing with the imprecise or vague nature of a linguistic assessment. To overcome this difficulty, the fuzzy multi-criteria decision-making methods are proposed. This paper presents an application of the analytic hierarchy process (AHP) method based on the fuzzy sets (Fuzzy AHP) used to select an appropriate site for a chromite processing plant in the Sistan and Baluchestan province. For this purpose, based on the concentration of chromite deposits in different regions of the province, four feasible alternatives including the Zahedan, Khash, Iranshahr, and Nikshahr cities are selected for a chromite processing plant. The quantitative and qualitative criteria such as availability of raw materials, availability of labors, education, climatic conditions, environmental impacts, infra-structural facilities and security, and local community considerations are used to compare the feasible alternatives. Finally, the alternatives are ranked, and a convenient location is recommended for the construction of the chromite processing plant. The results obtained show that the city of Zahedan is the best alternative.

**Keywords:** *Chromite Processing Plant, Sistan and Baluchestan Province, Fuzzy AHP.*

## 1. Introduction

One of the largest provinces in Iran is Sistan and Baluchestan, which is a rich region based on ore deposits. From the major metal mines of Sistan and Baluchestan, it can be mentioned that the chromite mines are located in different parts of the province. According to the existence of chromite deposits in the province, and also various applications of chromite in different industries such as the metallurgy, chemical, and pharmaceutical ones, it is expected that the establishment of a chromite processing plant is required in the erelong.

Selection of a plant location is a very important decision for firms because they are costly and almost irreversible, and they entail a long-term commitment. Also location decisions have an impact on the operating costs and revenues. For instance, a poor choice of location might result in excessive transportation costs, a shortage of qualified labor, loss of the competitive advantage, destructive effects on environment, inadequate supplies of raw materials, and some similar conditions that would be detrimental to the operations. The general procedure used for making location decisions usually consists of the following steps:

1. Decide on the criteria that will be used to evaluate the location alternatives.
2. Identify the criteria that are important.
3. Develop the location alternatives.
4. Evaluate the alternatives, and select the best one.

Site selection for a mineral processing plant is required to evaluate several alternatives with regard to a number of criteria. Therefore, this issue can be considered as a decision-making process, which is involved to find the best option among the feasible alternatives or to rank them.

Over the past decades, many methods such as simple additive weighting [1], the technique for order preference by similarity to ideal solution [1], analytical hierarchy process [2], and data envelopment analysis [3] have been developed to deal with a multiple decision-making problem. One of the most powerful and flexible decision-making methods is the analytical hierarchy process (AHP), which was initially presented by Saaty [2] for use in solving multiple-criteria decision-making problems.

Analytic hierarchy process (AHP) is one of the most commonly used multi-criteria decision-making (MCDM) methods, which integrates subjective and personal preferences in performing analyses. However, AHP involves human subjectivity, which introduces a vagueness type of uncertainty. Fuzzy logic, resembling human reasoning in its use of approximate information and certainty to generate decisions, is a better approach to convert linguistic variables to fuzzy numbers under ambiguous assessments, especially in geosciences, which suffer from insufficient and uncertain data. The traditional AHP has been modified to fuzzy AHP using fuzzy arithmetic operations, which provides more flexibility in an application.

This method, used under a fuzzy environment, has been used for a variety of specific applications in decision-making problems [4-17]. Nevertheless, its application in mineral processing site selection has not been reported yet.

This paper discusses the methodology and efficacy of the proposed FAHP in dealing with the selection of the most appropriate chromite processing plant site in the Sistan and Baluchestan province.

## 2. Fuzzy analytic hierarchy process (FAHP)

Analytic hierarchy process (AHP) is a useful approach used to evaluate the complex multiple criteria alternatives involving subjective judgment. AHP structures the decision problem in levels corresponding to one understanding the situation: goals, criterion, sub-criterion, and alternatives. By breaking the problem into levels, a decision-maker can focus on smaller sets of decisions. In the AHP technique, the elements of each level are compared to their related elements in an upper level by the pairwise comparison method. Though the aim of AHP is to capture a decision-maker's knowledge, the conventional AHP cannot fully reflect the human thinking style. Linguistic and vague descriptions could not be solved easily by AHP until the recent development in fuzzy decision-making [18, 19]. The fuzzy set theory was first proposed by Zadeh in 1965 as a means representing uncertainty using the set theory.

The traditional AHP employs exact numbers such as 1–9 to score. However, much decision-making involves some uncertainty. The traditional AHP does not take into account the uncertainty associated with the mapping of one's perception (or judgment) to a number [20].

The fuzzy set theory, resembling human reasoning in its use of approximate information and certainty to generate decisions, is a better approach to convert linguistic variables to fuzzy numbers under ambiguous assessments [21]. By incorporating the fuzzy set theory with AHP, the fuzzy AHP allows for a more accurate description of the decision-making process. Thus the use of fuzzy numbers and linguistic terms is more suitable since the traditional AHP approach is somewhat arbitrary. A fuzzy number describes the relationship between an uncertain quantity x and a membership function $\mu_x$, which ranges between 0 and 1. A fuzzy set is an extension of the classical set theory (in which x is either a member of set A or not), in which an x can be a member of set A with a certain membership function $\mu_x$. Different shapes of fuzzy numbers are possible (e.g. bell, triangular, trapezoidal, and Gaussian). In order to simplify the implementation, in this paper, triangular fuzzy numbers (TFNs) are used.

This paper proposes a seven-step procedure for FAHP, which is schematically given in Figure 1. A step-by-step description of the methodology is presented as follows.

### 2.1. Construction of hierarchical structures

Constructing the hierarchical model includes the decomposition of a complex decision problem into smaller manageable elements of different hierarchical levels. The first level of the hierarchy corresponds to the objective or goal, and the last one corresponds to the evaluation alternatives (options), whereas the intermediate levels correspond to the criteria and sub-criteria.

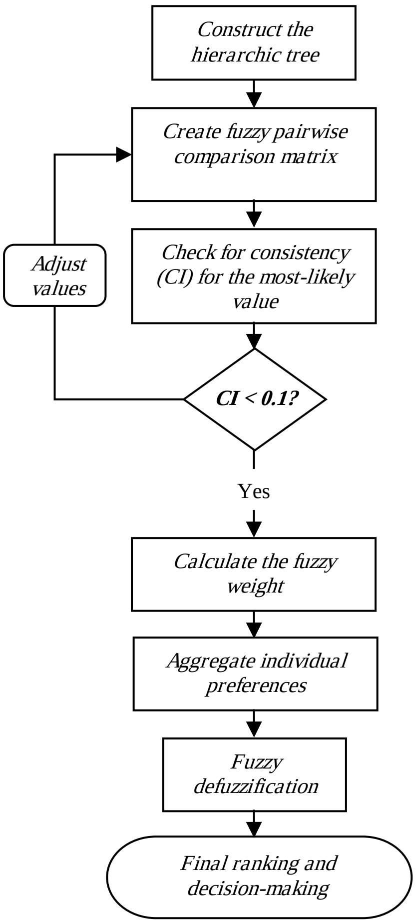


**Figure 1. Proposed methodology for fuzzy AHP.**

### 2.2. Development of fuzzy judgment matrix using pairwise comparisons

Within a hierarchical structure, the elements of a particular level are compared pairwise with a specific element of an upper level. A fuzzy judgment matrix ($\tilde{J}$) is generated using the fuzzy pairwise comparison index ($\tilde{j}_{ij}$). A relative importance of the pairwise comparison is assigned using a scale of 1–9 (Saaty, 1980), which are fuzzified to capture vagueness in perception and meaning (Table 1). For an *n* number of comparison items, the fuzzy judgment matrix $\tilde{J}$ is:

$$\tilde{J} = \begin{bmatrix} \tilde{j}_{11} & \tilde{j}_{12} & \cdots & \tilde{j}_{1n} \\ \tilde{j}_{21} & \ddots & & \tilde{j}_{2n} \\ \vdots & & \ddots & \vdots \\ \tilde{j}_{n1} & \tilde{j}_{n2} & \cdots & \tilde{j}_{nn} \end{bmatrix} \quad (1)$$

### 2.3. Check for consistency

Consistency is important in human thinking, which enables us to order the world according to dominance [22]. It is important to ensure that there is consistency in the pairwise comparisons. Therefore, it would be useful to have a measure of inconsistency associated with the pairwise comparison matrix $J$. In order to measure the degree of consistency, one can calculate the consistency index (CI). Consistency index, therefore, indicates whether a decision-maker provides consistent values (comparisons) in a set of evaluations. CI is calculated as:

$$CI = (\lambda_{max} - n)/(n - 1) \quad (2)$$

where $\lambda_{max}$ is the maximum eigenvalue, and n is the dimension of the judgment matrix.

The final inconsistency in the pairwise comparisons is solved using the consistency ratio $CR = CI/RI$, where RI is the random index, which is obtained by averaging the CI of a randomly generated reciprocal matrix [2]. The RI values are tabulated in Table 2. The threshold of CR is 0.1, and in the case of exceedance, a three-step procedure should be followed [22]: (1) identify the most inconsistent judgment in the decision matrix, (2) determine a range of values the inconsistent judgment can be changed to, so that the associated inconsistency would be reduced, and (3) ask the decision-maker to reconsider the judgment to a 'reasonable value'. In this paper, though the pairwise comparison indices of the judgment matrix are TFNs, however, CI is evaluated for the most likely value.

**Table 1. Fuzzy scales for pairwise comparisons.**

| Relative importance | *Fuzzy scale | Verbal judgment of preference |
|---|---|---|
| $\overline{1}$ | (1, 1, 1) | Equal importance |
| $\overline{3}$ | (3-δ, 3, 3+δ) | Moderate importance |
| $\overline{5}$ | (5-δ, 5, 5+δ) | Strong importance |
| $\overline{7}$ | (7-δ, 7, 7+δ) | Very strong importance |
| $\overline{9}$ | (8, 9, 9) | Extreme importance |
| $\overline{2}, \overline{4}, \overline{6}, \overline{8}$ | (*x*-δ, *x*, *x*+δ) | Intermediate values between adjacent scale values |
| $1/\overline{x}$ | (1/(*x*+δ), 1/*x*, 1/(*x*-δ)) | |
| $1/\overline{9}$ | (1/9, 1/9, 1/8) | |

*δ is a fuzzification factor.

**Table 2. Random inconsistency (RI) indices.**

| No. of criteria | 1-2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| RI | 0 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

## 2.4. Calculation of fuzzy weights

In this paper, for the ease of implementation, the geometric mean is adopted to estimate the weights.

Fuzzy arithmetic operations are utilized over matrix $\tilde{J}$ to compute the fuzzy weights. The geometric mean is computed for each row $\tilde{J}_i$. Given $\tilde{J}$ from Eq. 1, the corresponding fuzzy weights are computed as:

$$\tilde{J}_i = (\tilde{j}_{i1} \otimes \cdots \otimes \tilde{j}_{in})^{\frac{1}{n}} \tag{3}$$

$$\tilde{w}_i = \tilde{J}_i \otimes (\tilde{J}_1 \oplus \cdots \oplus \tilde{J}_n)^{-1} \tag{4}$$

Where $\tilde{w}_i$ is the fuzzy weight (where i = 1 to n).

## 2.5. Establishment of global preference weights

The local priorities at each level are aggregated to obtain the final preferences of the alternative. This computation is carried out by the evaluation of the alternatives to the top level (goal). Therefore, at each level k of the hierarchical tree, the fuzzy global preference weights ($\tilde{G}_k$) are computed as:

$$\tilde{G}_k = \tilde{w}_k \cdot \tilde{G}_{k-1} \tag{5}$$

The final fuzzy AHP score ($\tilde{F}_{Ai}$) for each alternative $A_i$ is obtained by carrying out the fuzzy arithmetic sum over each global preference weight:

$$\tilde{F}_{Ai} = \sum_{k=1}^{n} \tilde{G}_k \text{ for each alternative } A_i \tag{6}$$

## 2.6. Ordering alternatives using fuzzy ranking methods

The defuzzification entails converting the final fuzzy AHP score $\tilde{F}_{Ai}$ into a crisp value. Once the final fuzzy AHP score ($\tilde{F}_{Ai}$) of each alternative is defuzzified, the crisp numbers are compared and ranked accordingly. In this work, the most common centroid index method, developed by Yager in 1980 [23], was employed. The index is a geometric center $x_O(A_i)$ of the fuzzy number of alternative $A_i$, where for a given TFN, ($a_1$, $b_1$, $c_1$) is formulated as follows:

$$x_O(A_i) = \frac{\int_0^1 A_i \mu_{Ai}(x)dx}{\int_0^1 \mu_{Ai}(x)dx} = \frac{(b_1 - a_1)(a_1 + \frac{2}{3}(b_1 - a_1)) + (c_1 - b_1)(b_1 + \frac{1}{3}(c_1 - b_1))}{(b_1 - a_1) + (c_1 - b_1)} \tag{7}$$

where $A_i$ is treated as a moment arm (weight function), measuring the importance of the *x* value. The value for $x_O(A_i)$ may be seen as the weighted mean value of the fuzzy number $A_i$. Hence, the bigger the $x_O(A_i)$ values are, the better will be the ranking of an alternative.

# 3. Application of FAHP to chromite processing plant site selection in Sistan and Baluchestan province

## 3.1. Chromite reserve in Sistan and Baluchestan province

The Sistan and Baluchestan province is one of the rich areas of mineral deposits in the SE of Iran. One of the important metallic mineral deposits is chromite, which can be found in various parts of the province. Distribution of the chromite deposits in the province is illustrated in Figure 2. The red spots in this figure represent the chromite deposits. It can be clearly seen that the chromite mines are concentrated around Zahedan, Khash, Nikshahr, and Iranshahr.

## 3.2. Chromite processing plant site selection in Sistan and Baluchestan province

The first step in the process of site selection is collecting and evaluating the required information. Selection of an appropriate site for mineral processing plant involves considering many criteria. The large number of criteria leads to a computational difficulty, a time-consuming process, and an unrealistic outcome.

The decision-making criteria for chromite processing plant site selection in the Sistan and Baluchestan province include availability of raw materials (C1), availability of labors (C2), education (C3), climatic conditions (temperature, humidity, precipitation, number of dusty days per year, etc.) (C4), environmental impacts (C5), infra-structural facilities (C6), and security and local community considerations (C7). Also by evaluating the distribution map of chromite deposits in the Sistan and Baluchistan province, the feasible alternatives are those locations where the chromite deposits are more concentrated. The selected locations are Zahedan (A1), Khash (A2), Iranshahr (A3), and Nikshahr (A4). Each alternative is evaluated with relevant criteria based on the technical and experimental experiences, and also by asking the decision-makers and experts.

Based on the criteria and feasible alternatives, a hierarchical tree involved in the selection of four alternatives is illustrated in Figure 3. Then a pairwise comparison matrix for level 2 criteria (C1 to C7) to select the most appropriate chromite processing plant site is built as in Table 3.

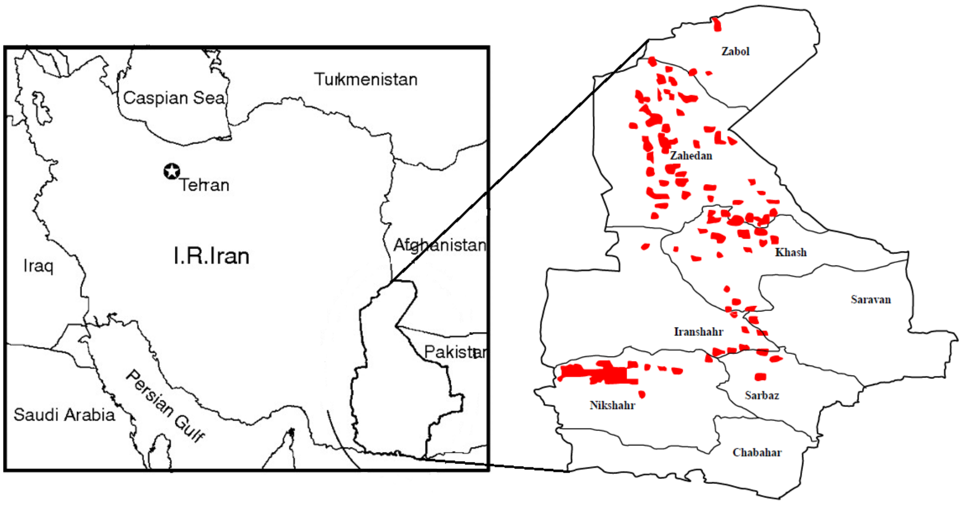


**Figure 2. Location and distribution of chromite deposits in Sistan and Baluchestan province (red spots represent chromite deposits).**

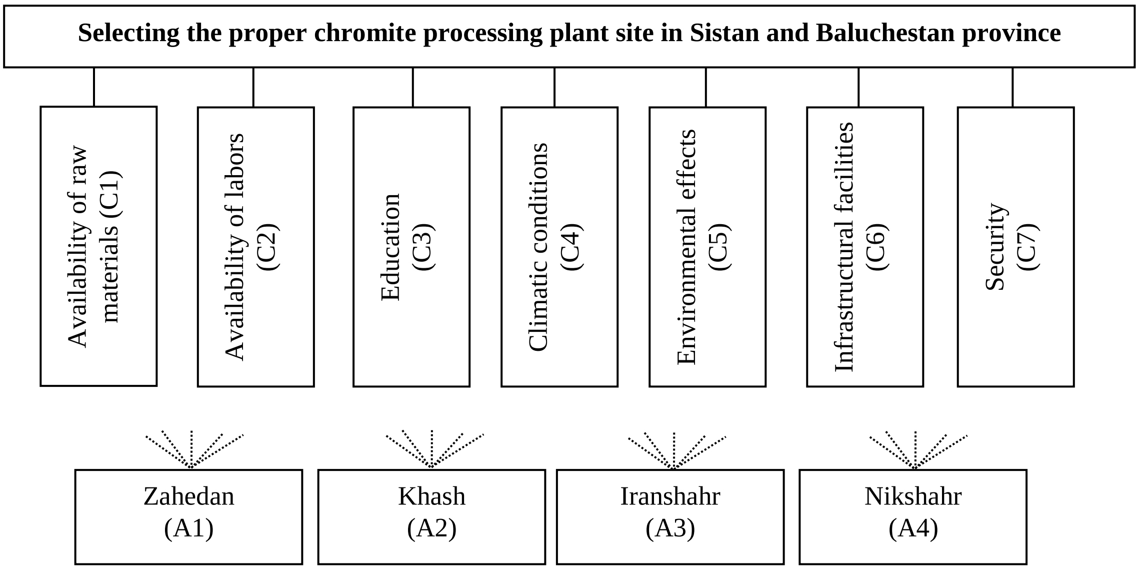


**Figure 3. Hierarchical structure for selection of chromite processing plant site.**

**Table 3. Fuzzy pair-wise comparison matrix.**

| | C1 | C2 | C3 | C4 | C5 | C6 | C7 |
|---|---|---|---|---|---|---|---|
| **C1** | $\overline{1}$ | $\overline{5}$ | $\overline{7}$ | $\overline{2}$ | $\overline{3}$ | $\overline{7}$ | $\overline{3}$ |
| **C2** | $1/\overline{5}$ | $\overline{1}$ | $\overline{3}$ | $1/\overline{5}$ | $1/\overline{5}$ | $\overline{3}$ | $1/\overline{5}$ |
| **C3** | $1/\overline{7}$ | $1/\overline{3}$ | $\overline{1}$ | $1/\overline{7}$ | $1/\overline{5}$ | $\overline{3}$ | $1/\overline{5}$ |
| **C4** | $1/\overline{2}$ | $\overline{5}$ | $\overline{7}$ | $\overline{1}$ | $\overline{2}$ | $\overline{7}$ | $\overline{2}$ |
| **C5** | $1/\overline{3}$ | $\overline{5}$ | $\overline{5}$ | $1/\overline{2}$ | $\overline{1}$ | $\overline{7}$ | $1/\overline{2}$ |
| **C6** | $1/\overline{7}$ | $1/\overline{3}$ | $1/\overline{3}$ | $1/\overline{7}$ | $1/\overline{7}$ | $\overline{1}$ | $1/\overline{7}$ |
| **C7** | $1/\overline{3}$ | $\overline{5}$ | $\overline{5}$ | $1/\overline{2}$ | $\overline{2}$ | $\overline{7}$ | $\overline{1}$ |

After forming the fuzzy pairwise comparison matrix, the geometric mean is computed for each criterion $\tilde{J}_i$ using Eq. (3):

$$\tilde{J}_1 = (\bar{1} * \bar{5} * \bar{7} * \bar{2} * \bar{3} * \bar{7} * \bar{3})^{\frac{1}{7}} = (2.4794, 3.3161, 4.0679)$$
$$\tilde{J}_2 = (\bar{\tfrac{1}{5}} * \bar{1} * \bar{3} * \bar{\tfrac{1}{5}} * \bar{\tfrac{1}{5}} * \bar{3} * \bar{\tfrac{1}{5}})^{\frac{1}{7}} = (0.4379, 0.5456, 0.6730)$$
$$\tilde{J}_3 = (\bar{\tfrac{1}{7}} * \bar{\tfrac{1}{3}} * \bar{1} * \bar{\tfrac{1}{7}} * \bar{\tfrac{1}{5}} * \bar{3} * \bar{\tfrac{1}{5}})^{\frac{1}{7}} = (0.2997, 0.3621, 0.4453)$$
$$\tilde{J}_4 = (\bar{\tfrac{1}{2}} * \bar{5} * \bar{7} * \bar{1} * \bar{2} * \bar{7} * \bar{2})^{\frac{1}{7}} = (1.7385, 2.4228, 3.2027)$$
$$\tilde{J}_5 = (\bar{\tfrac{1}{3}} * \bar{5} * \bar{5} * \bar{\tfrac{1}{2}} * \bar{1} * \bar{7} * \bar{\tfrac{1}{2}})^{\frac{1}{7}} = (1.1504, 1.4664, 2.0339)$$
$$\tilde{J}_6 = (\bar{\tfrac{1}{7}} * \bar{\tfrac{1}{3}} * \bar{\tfrac{1}{3}} * \bar{\tfrac{1}{7}} * \bar{\tfrac{1}{7}} * \bar{7} * \bar{\tfrac{1}{7}})^{\frac{1}{7}} = (0.2051, 0.2403, 0.2947)$$
$$\tilde{J}_7 = (\bar{\tfrac{1}{3}} * \bar{5} * \bar{5} * \bar{\tfrac{1}{2}} * \bar{2} * \bar{7} * \bar{1})^{\frac{1}{7}} = (1.3459, 1.7876, 2.3796)$$

Then weights of all criteria are calculated using Eq. (4):

$$\tilde{w}_1 = \tilde{J}_1 * (\tilde{J}_1 + \tilde{J}_2 + \tilde{J}_3 + \tilde{J}_4 + \tilde{J}_5 + \tilde{J}_6 + \tilde{J}_7)^{-1} = (0.1893, 0.3270, 0.5313)$$
$$\tilde{w}_2 = \tilde{J}_2 * (\tilde{J}_1 + \tilde{J}_2 + \tilde{J}_3 + \tilde{J}_4 + \tilde{J}_5 + \tilde{J}_6 + \tilde{J}_7)^{-1} = (0.0334, 0.0538, 0.0879)$$
$$\tilde{w}_3 = \tilde{J}_3 * (\tilde{J}_1 + \tilde{J}_2 + \tilde{J}_3 + \tilde{J}_4 + \tilde{J}_5 + \tilde{J}_6 + \tilde{J}_7)^{-1} = (0.0229, 0.0357, 0.0582)$$
$$\tilde{w}_4 = \tilde{J}_4 * (\tilde{J}_1 + \tilde{J}_2 + \tilde{J}_3 + \tilde{J}_4 + \tilde{J}_5 + \tilde{J}_6 + \tilde{J}_7)^{-1} = (0.1327, 0.2389, 0.4183)$$
$$\tilde{w}_5 = \tilde{J}_5 * (\tilde{J}_1 + \tilde{J}_2 + \tilde{J}_3 + \tilde{J}_4 + \tilde{J}_5 + \tilde{J}_6 + \tilde{J}_7)^{-1} = (0.0878, 0.1446, 0.2656)$$
$$\tilde{w}_6 = \tilde{J}_6 * (\tilde{J}_1 + \tilde{J}_2 + \tilde{J}_3 + \tilde{J}_4 + \tilde{J}_5 + \tilde{J}_6 + \tilde{J}_7)^{-1} = (0.0157, 0.0237, 0.0385)$$
$$\tilde{w}_7 = \tilde{J}_7 * (\tilde{J}_1 + \tilde{J}_2 + \tilde{J}_3 + \tilde{J}_4 + \tilde{J}_5 + \tilde{J}_6 + \tilde{J}_7)^{-1} = (0.1028, 0.1763, 0.3108)$$

The computed fuzzy weights are summarized for each criterion in Table 4.

For a fuzzification factor δ =1, evaluation of the final global preference weights, $\tilde{G}_2 = \tilde{w}_2 \cdot \tilde{G}_1$, for the four alternative are summarized in Table 5. The final fuzzy AHP scores $\tilde{F}_{Ai}$ (Table 5) for each alternative (Zahedan, Khash, Iranshahr, and Nikshahr) were evaluated as (0.167, 0.427, 1.068), (0.107, 0.274, 0.698), (0.082, 0.198, 0.497), and (0.041, 0.101, 0.262), respectively. The sum of the most likely values is equal to one (0.427+0.274+0.198+0.101), whereas the sum of the minimum values (0.167+0.107+0.082+0.041) <1, and the sum of the maximum values (1.068+0.698+0.497+0.262)>1. The difference between the sum of the minimum values and the sum of the maximum values represents the overall uncertainty (vagueness) in the decision-making process.

In the final ranking of the fuzzy AHP score $\tilde{F}_{Ai}$, the option with the highest score is ranked the best. Here, the Yager's centroid index [23] is used for defuzzification to rank the alternatives.

The final defuzzified values for the Zahedan, Khash, Iranshahr, and Nikshahr cities are summarized in Table 6. According to the final score obtained for each option (city), Zahedan was rated as the best city for the chromite processing plant construction.

**Table 4. Fuzzy local weights for criteria, $\tilde{w}_i$ $(i = 1, 2)$.**

| L. 2 | $W_1$ | $W_2$ (Zahedan) | $W_2$ (Khash) | $W_2$ (Iranshahr) | $W_2$ (Nikshahr) |
|---|---|---|---|---|---|
| C1 | (0.1893, 0.3270, 0.5313) | (0.071, 0.096, 0.139) | (0.071, 0.096, 0.139) | (0.158, 0.250, 0.393) | (0.375, 0.558, 0.809) |
| C2 | (0.0334, 0.0538, 0.0879) | (0.053, 0.081, 0.143) | (0.069, 0.114, 0.188) | (0.153, 0.249, 0.403) | (0.365, 0.556, 0.830) |
| C3 | (0.0229, 0.0357, 0.0582) | (0.038, 0.052, 0.075) | (0.079, 0.118, 0.188) | (0.128, 0.198, 0.289) | (0.469, 0.633, 0.850) |
| C4 | (0.1327, 0.2389, 0.4183) | (0.115, 0.160, 0.238) | (0.303, 0.397, 0.511) | (0.303, 0.397, 0.511) | (0.037, 0.047, 0.063) |
| C5 | (0.0878, 0.1446, 0.2656) | (0.042, 0.061, 0.093) | (0.174, 0.255, 0.409) | (0.174, 0.255, 0.409) | (0.228, 0.429, 0.709) |
| C6 | (0.0157, 0.0237, 0.0385) | (0.083, 0.121, 0.201) | (0.083, 0.121, 0.201) | (0.115, 0.220, 0.385) | (0.336, 0.538, 0.836) |
| C7 | (0.1028, 0.1763, 0.3108) | (0.049, 0.074, 0.128) | (0.072, 0.122, 0.212) | (0.119, 0.202, 0.322) | (0.415, 0.603, 0.866) |

**Table 5. Evaluation of final global preference weights for alternatives, $\tilde{G}_2 = \tilde{w}_2 \cdot \tilde{G}_1$.**

| Criteria | Zahedan | Khash | Iranshahr | Nikshahr |
|---|---|---|---|---|
| Availability of raw materials | (0.071, 0.182, 0.430) | (0.030, 0.082, 0.209) | (0.014, 0.031, 0.074) | (0.014, 0.031, 0.074) |
| Availability of labors | (0.012, 0.030, 0.073) | (0.005, 0.013, 0.035) | (0.002, 0.006, 0.016) | (0.002, 0.004, 0.013) |
| Education | (0.011, 0.023, 0.049) | (0.003, 0.007, 0.017) | (0.002, 0.004, 0.011) | (0.001, 0.002, 0.004) |
| Climatic conditions | (0.005, 0.011, 0.026) | (0.040, 0.095, 0.214) | (0.040, 0.095, 0.214) | (0.015, 0.038, 0.099) |
| Environmental impacts | (0.020, 0.062, 0.188) | (0.015, 0.037, 0.109) | (0.015, 0.037, 0.109) | (0.004, 0.009, 0.025) |
| Infra-structural facilities | (0.005, 0.013, 0.032) | (0.002, 0.005, 0.015) | (0.001, 0.003, 0.008) | (0.001, 0.003, 0.008) |
| Security | (0.043, 0.106, 0.269) | (0.012, 0.036, 0.100) | (0.007, 0.021, 0.066) | (0.005, 0.013, 0.040) |
| $\tilde{F}_{Ai} \sum \tilde{G}_2$ | (0.167, 0.427, 1.068) | (0.107, 0.274, 0.698) | (0.082, 0.198, 0.497) | (0.041, 0.101, 0.262) |

**Table 6. Ranking of alternatives using defuzzification method.**

| Alternative | Centroid, $x_o(A_i)$ | Rank |
|---|---|---|
| Zahedan city | 0.5539 | 1 |
| Khash city | 0.3599 | 2 |
| Iranshahr city | 0.2589 | 3 |
| Nikshahr city | 0.1348 | 4 |

## 4. Conclusions

Selection of a processing plant location is a complicated multi-criteria decision-making process, and uncertainty, complexity, and hierarchy are the most important factors in terms of its characteristics. In this paper, a practical approach was presented for selecting and weighing the chromite processing plant location problem based on the fuzzy AHP method.

The decision criteria were availability of raw materials, availability of labors, education, climatic conditions, environmental impacts, infra-structural facilities and security, and local community considerations. These criteria were evaluated to determine the order of location alternatives for selecting the most appropriate one. The location alternatives included Zahedan (A1), Khash (A2), Iranshahr (A3), and Nikshahr (A4). Using the fuzzy AHP, the best alternative was Zahedan, and the ranking order of the alternatives was as follows: Zahedan > Khash > Iranshahr > Nikshahr.

The application of this approach to the real case shows that the fuzzy AHP method is easy to use and understand by the experts. Application of the fuzzy AHP method for the complex problem of selection of a chromite processing plant location was carried out in this study for the first time. The fuzzy AHP method is preferred when the criteria weights and performance ratings are vague and inaccurate. An appropriate decision-making method should be taken into account according to the situation and structure of the problem. In future studies, other multi-criteria methods like fuzzy TOPSIS and ELECTRE can be used to handle plant location selection problems. Also the proposed methods can be applied to other multi-criteria decision problems like supplier selection, personnel selection, and machine selection of companies.

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# انتخاب مکان کارخانه فرآوری کرومیت با استفاده از فرآیند تحلیل سلسله مراتبی فازی

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**چکیده:**

با توجه به ذخایر کرومیت در استان سیستان و بلوچستان و همچنین کاربردهای مختلف کرومیت در صنایع مختلف نیاز به کارخانه فرآوری کرومیت در آینده نه چندان دور پیش‌بینی می‌شود. موقعیت جغرافیایی کارخانه فرآوری می‌تواند تأثیر فراوانی در موفقیت سرمایه‌گذاری صنعتی داشته باشد. مکان‌یابی کارخانه فرآوری یک مسئله تصمیم‌گیری چند معیاره است. در انتخاب مکان کارخانه از آنجایی که اغلب معیارها توسط ادراک و قضاوت‌های افراد ارزیابی می‌شوند و به علت طبیعت مبهم ارزیابی‌های لفظی از تصمیم‌گیری چند معیاره مبتنی بر منطق فازی استفاده می‌شود. در این تحقیق برای انتخاب مکان مناسب احداث کارخانه فرآوری کرومیت در استان سیستان و بلوچستان از فرآیند تحلیل سلسله مراتبی فازی استفاده شده است. بدین منظور، بر اساس تراکم ذخایر کرومیت در نقاط مختلف استان، چهار مکان شامل شهرستان‌های زاهدان، خاش، ایرانشهر و نیکشهر برای احداث کارخانه فرآوری کرومیت در نظر گرفته شده است. معیارهای کمّی و کیفی از قبیل دسترسی به مواد اولیه، نیروی کار در دسترس، آموزش، شرایط آب و هوا، آثار زیست‌محیطی، امکانات زیربنایی، امنیت و ملاحظات اجتماعی برای مقایسه مکان‌های احتمالی استفاده شده است. در نهایت محل‌های احتمالی برای احداث کارخانه فرآوری کرومیت امتیازدهی شد و محل مناسب پیشنهاد شده است. نتایج به دست آمده نشان می‌دهد که شهرستان زاهدان مناسب‌ترین گزینه برای احداث کارخانه فرآوری کرومیت در استان سیستان و بلوچستان است.

**کلمات کلیدی:** کارخانه فرآوری کرومیت، استان سیستان و بلوچستان، فرآیند تحلیل سلسله مراتبی فازی.