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Comparing Two Methods of PROMETHEE and Fuzzy TOPSIS in Selecting the Best Plant Species for the Reclamation of Sarcheshmeh Copper Mine

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Abstract: Mining affects the environment around the extracted area negatively. As a result, it is vital to rehabilitate mines and reclamate the region to its former natural condition or use the land in an optimized way. The choice of herbal types and planting them to conserve the natural environment of the region and reclamating the mine is of utmost importance. When a case study was conducted in Sarcheshmeh copper mine which is one of the 10 biggest copper mines of the world, plant species were selected according to the initial factors of the rehabilitation scheme, climatic conditions and soil conditions. Then, secondary factors were identified and decision matrices that are based on questionnaires completed by experts, plant species based on regional perspective criteria, resistance to disease and insects, their strength and development, access to the plant species, economic efficiency, soil conservation and water saving, prevention of various types of contamination were all classified according to the multi-criteria decision making methods. It is worth saying that the weights of the criteria are compared with the use of PROMETHEE and Fuzzy TOPSIS methods. The best plant species in the mining area and tailing dam prioritized by PROMETHEE method are mountain almonds (2.28), tamarisk (1.44), ephedra (0.55), pistacia (0.44), Astragalus (–2.22), and salsola (–2.48).

Key words: PROMETHEE, Fuzzy AHP, Fuzzy TOPSIS, mountain almond.

Introduction

Reclamation commonly refers to preparation of extracted lands for reuse and the term is mostly used for surface mines. Mine reclamation as an inseparable part of the mining design as a whole must be taken into consideration in the first phases of mining operations. The goal of the reclamation is preserving natural environment and creating a better climate for the region. Altogether, the mining site must be reestablished so that the land reuse and morphology of the mining site or the natural environment are consistent (Soltanmohammadi et al., 2010).

Most methods that are used for the reclamation of the polluted lands under the scrutiny of geochemistry, hydrology, ecology and environment experts, have three phases: removing the source of the pollution, not using the mining site, and rehabilitating the site (Alavi et al., 2012). Selecting and implanting plant species is one of the important phases in reclamating the mine for

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further use of the effected lands and helping to protect its natural environment (Xia et al., 2007). The selected plants, must be resistant to the unfavourable conditions of the soil in the mining region. This plays a vital role in reclamating the mining area lands (Haque et al., 2009). The proper acidity for plants to grow is 6.5 to 7.5 (Akbari et al., 2007).

The indigenous plant species adapt better to the climatic conditions of the area, and if any manure or fertilizer was to be added, the growth conditions would improve (Redente and Baker., 1996). Coppin and Bradshaw (1982), Tafi (2006) and Craig and Kruger (2007) evaluated the limiting factors of the plant growth in mined soils. Cairns (1972) and Errington (2001) conducted researches about reusing the mined lands. The impact of plant cultivation on mined lands was examined by Alexander (1998) and Paschke (2003). Akbari et al. (2007) identified the type of reuse of mined land. Soltanmohammadi et al. (2008) examined possible uses of mineral extracted land using AHP ELECTRE and TOPSIS methods.

Osanloo and Parsaei (2004) conducted a study on reclamation of Sarcheshmeh copper mine. Bangian and Osanloo (2008) carried out the selection of plant species for the reclamation of Sungun copper mine by the use of hierarchical analysis method. Alavi et al. (2009) obtained the best plant species by the use of the fuzzy AHP method to reclamate Sarcheshmeh copper mine. Considering that since now the selection of plant species was not carried out using a PROMETHEE method, therefore in this paper a PROMETHEE approach was used to prioritize and select the most suitable plant species for the reclamation of Sarcheshmeh copper mine. The PROMETHEE method has been well-known by academics and researchers and many articles have been written using this technique (Behzadian et al., 2009).

According to these studies when the options do not match (for example when an option has a better performance benchmark and another option based on another criterion which is also the case in this study), PROMETHEE applications like other multi-criteria methods such as hierarchical analytics, etc. are useful for comparing options (Soltanmohammadi et al., 2008). However, PROMETHEE method is advantageous in comparison with methods such as hierarchical analysis, since hierarchical analysis has the probability of the human error and when the number of criteria and options is high, due to increased number of the interactions, calculations are tedious and time-consuming (Niknafas et al., 2010). Furthermore, the limitation of hierarchical method on a scale of 1 to 9 is one of its weaknesses (especially when there is little data) (Zak and Sawicka, 2010). The PROMETHEE disadvantage is that it does not offer an approach for weighing the criteria and rather leaves it to the decision maker (Macharis et al., 2007).

In this paper, first we focus on the theoretical basis on how to select and prioritize plant species in a mine restructuring plan. Then, in the case of Sarcheshmeh copper mine, a few explanations are presented and Fuzzy logic and multi-criteria decision-making methods are explained and after that, in order to select the best plant for the reclamation of the Sarcheshmeh copper mine, the PROMETHEE and Fuzzy TOPSIS methods are used and their results are compared. As mentioned, in the PROMETHEE method, no approach is presented for weighing the criteria; therefore a Fuzzy hierarchical analysis method that gives acceptable results was used to weigh the criteria. This method will be briefly discussed.

Theoretical Basis

The Importance of Selecting Plant Species in the Reclamation of the Mine

In the process of the reclamation of the mine, planting and creating green space for the region is a necessary step in order to reuse the extracted land. As a result, selecting plant species is one of the basic steps in achieving the objectives of the reclamation plan. Selecting superior plant species in each regeneration programme has several advantages such as maintaining the health and rehabilitating the environment, region's scenery, economic benefits, welfare of the people living in the region, reducing soil and climate pollution, underground water storage and preventing soil erosion (Bangian and Osanloo, 2008). There are two factors influencing the selection of plant species: Primary factors, and secondary factors. The primary factors are those that the selected plant species must be fit for and coordinated with. However, secondary factors are those which include the conditions of the region and according to which selected plant species will be prioritized to each other (Osanloo, 2000).

Selecting Plant Species According to Primary Factors

Plant species should be consistent with the initial factors. As a result, at this stage only species that are compatible with the land reuse, pass to the next stage. In the next stage, the existing species are evaluated in accordance with the climatic conditions of the region and other options are nullified. The quality of the soil as the third of the primary factors among selected species based on the first and second factors, reject some of the options.

Prioritizing Plant Species Based on Secondary Factors

Secondary factors are: Region landscape, resistance to disease, human aggression, potency and growth, compatibility with other species in the region, economic efficiency, insect resistance, soil conservation, water supply, prevention of various types of contamination, and access to plant species.

Case Study

The city of Rafsanjan is on the southern edge of the Lut desert and in the northwest of Kerman province. The coordination of the city is 30°N latitude and 56°E longitude. The coordination of Sarcheshmeh copper mine is N55° 52′20″ E29° 56′40″, and its average altitude from the sea is 2620 metres, and it is one of 10 biggest copper mines in the world. Sarcheshmeh copper mine is located 65 kilometres southwest of Rafsanjan. This copper mine is located southeast of Iran. Porphyry copper has a fault and is remained from Tertiary period with a volcanic sedimentary formation. The region's rocks are composed of volcanic sedimentary complexes of the Oligocene and quaternary Dacite lavas.

Since the beginning of the year till the end of December 32 million 588 thousand and 944 tons of ore were mined from Sarchesmeh copper mine which is seven percent beyond the mining programme. According to the latest report from Sarcheshmeh Copper Complex, the reserve volume of 120 million tons copper ore have average grade of 0.2%.

Research Methodology

Decision Making

Multi-criteria decision-making models have been developed to assist the correct and scientific decision and are divided into two groups of Multiple Objective Decision Making (MODM) (non-countable) and Multiple Attribute Decision Making (MADM) models (countable). MODM models (such as ideal planning and data panels) are often used for designing, targeting, and simultaneously optimizing multiple targets (Mansour Momeni, 2007; Mehdi Taherkhani, 2006). MADM models are used to evaluate, prioritize and choose between different options based on specific criteria (and in some cases the contradictory ones) which are also commonly used for weighting (Chou et al., 2005; Brans and Mareschal, 2004). These criteria usually explain the features of the options. As a matter of fact, it decides how to choose the best option among the available options, so that the options that you choose can bring you the most benefit and success.

Fuzzy Logic

Fuzzy Logic is a very important branch of logic that was introduced by Professor Lotfizadeh in 1965 and contrasted to Aristotle's binary logic. Fuzzy theory provides the ground for reasoning, deduction, control and decision-making in ambiguous conditions and transforms qualitative judgements into quantitative ones (Zadeh, 1965). Lotfizadeh (1965) introduced the theory of fuzzy sets as a method for modelling in ambiguity and lack of certainty. A typical binary set has two values and the membership function can only take 0 or 1. This means, it is either zero (employee is not a member of the set) or one (employee is a member of the set). But in the fuzzy set, degrees are between 0 and 1 and the concept of graded membership is introduced. Fuzzy logic is used to determine the grade of membership and the grade of membership of an element from a set is determined between the two states of zero and one. Fuzzy is the spectrum between black and white or gray that allows us to make models for general uncertain real-world conditions (Zadeh, 1965).

With this theory, Lotfizadeh expressed the uncertainty surrounding the ambiguity of human thought and the main advantage of this theory was the ability to provide uncertain ambiguous data. One of the most vital and efficient applications of this theory in comparison with the theories of classical sets is the application of fuzzy sets in decision-making issues. In fact, fuzzy decision-making theory attempts to model the ambiguity and inherent uncertainties in the preferences, goals, and constraints of decision making issues. Human thoughts are associated with uncertainty and this uncertainty affects decision making. That's why, fuzzy decision-making methods are used.

Fuzzy Technique for Order-Preference by Similarity to Ideal Solution (F. TOPSIS)

This is one of the Multiple Attribute Decision Making methods. This method was initially provided by Yoon and Hwang. The basic concept of this method is that it should have the option of the shortest distance from the ideal positive solution and the furthest distance from the ideal negative solution. Chen (2000) developed TOPSIS in a Fuzzy environment. The algorithm of this method is as follows (Momeni, 2009):

1. The decision matrix is formed according to Table 1. Fuzzy numbers to express the linguistic variables in the decision matrix are defined (1 to 9). Very low is [1, 2, 3], low is [2, 3, 5], average is [3, 5, 7], high is [5, 7, 9], very high is [7, 9, 9].

2. The weight of the criteria is determined. The AHP Fuzzy method were calculated by the use of the formulas 8 to 11 according to Table 2.

3. Without making the decision matrix: the highest number in each column is selected for the positive criterion, then all the layers are split into it. The lowest number for each column is selected for the negative criterion and divided into all the layers (it should be noted that the lower boundaries and the upper bound are changed in the denominator). Since all criteria in this research are positive, the formulas are based on positive criterion.

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{cj*}, \frac{b_{ij}}{cj*}, \frac{c_{ij}}{cj*}\right) \quad cj^{+} = \max_j c_{ij} \tag{1}$$

4. Formation of unmatched matrix

$$\tilde{V}_{ij} = \tilde{r}_{ij(.)}\tilde{W}_{ij} \tag{2}$$

5. Determination of fuzzy ideal and fuzzy anti-ideal solutions (FPIS and FNIS). Ideal solution in each column for the positive criterion is the maximum for the third component and for the negative criterion is the minimum for the third component. An ideal solution for the negative criterion is the minimum of the first component and the maximum of the first component in each column.

$$Vj^{-} = \min_i \{\tilde{v}_{ij1}\} \tag{3}$$

$$Vj^{+} = \max_i \{\tilde{v}_{ij3}\} \tag{4}$$

6. Determination of the distance from the ideal and anti-ideal solution shown in Tables 3 and 4.

$$d_1^{+} = \sqrt{\frac{1}{3}\sum\nolimits_{j=1}^{n}(\tilde{V}_{ij} - V_j^{+})^2} \tag{5}$$

$$d_1^{-} = \sqrt{\frac{1}{3}\sum\nolimits_{j=1}^{n}(\tilde{V}_{ij} - V_j^{-})^2} \tag{6}$$

7. Determination of similarity index (proximity coefficient)

$$CC = \frac{d^{-}}{d^{-} + d^{+}} \tag{7}$$

Table 1: Decision matrix in Fuzzy TOPSIS method

	C1			*C2*			*C3*			*C1*			*C0*			*C5*			*C2*		
A1	5	7	9	2	3	5	2	3	5	5	7	9	3	5	7	7	9	9	7	9	9
A2	3	5	7	3	5	7	5	7	9	7	9	9	5	7	9	5	7	9	5	7	9
A3	3	5	7	5	7	9	3	5	7	5	7	9	3	5	7	3	5	7	5	7	9
A4	2	3	5	3	5	7	3	5	7	5	7	9	2	3	5	3	5	7	2	3	5
A5	3	5	7	3	5	7	2	3	5	5	7	9	2	3	5	3	5	7	2	3	5
A6	5	7	9	5	7	9	3	5	7	5	7	9	2	3	5	5	7	9	3	5	7

Table 2: Relative weights of criteria compared to each other

V(S1>-S2)-	0.869	V(S1>-S3)-	0.869	V(S1>-S4)-	1.000	V(S1>-S5)-	1.000	V(S1>-S6)-	0.869	V(S1>-S7)-	0.869
V(S2>-S1)-	1.000	V(S2>-S3)-	1.000	V(S2>-S4)-	1.000	V(S2>-S5)-	1.000	V(S2>-S6)-	1.000	V(S2>-S7)-	1.000
V(S3>-S1)-	1.000	V(S3>-S2)-	1.000	V(S3>-S4)-	1.000	V(S3>-S5)-	1.000	V(S3>-S6)-	1.000	V(S3>-S7)-	1.000
V(S4>-S1)-	0.831	V(S4>-S2)-	0.679	V(S4>-S3)-	0.679	V(S4>-S5)-	1.000	V(S4>-S6)-	1.637	V(S4>-S7)-	0.679
V(S5>-S1)-	0.576	V(S5>-S2)-	0.404	V(S5>-S3)-	0.404	V(S5>-S4)-	0.764	V(S5>-S6)-	1.549	V(S5>-S7)-	0.404
V(S6>-S1)-	1.000	V(S6>-S2)-	1.000	V(S6>-S3)-	1.000	V(S6>-S4)-	1.000	V(S6>-S5)-	1.000	V(S6>-S7)-	1.000
V(S7>-S1)-	1.000	V(S7>-S2)-	1.000	V(S7>-S3)-	1.000	V(S7>-S4)-	1.000	V(S7>-S5)-	1.000	V(S7>-S6)-	1.000

Table 3: Options intervals from the ideal solution

Distance	*C1*	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*
d(A1,A+)	0.042	0.108	0.108	0.033	0.033	0.022	0.022
d(A2,A+)	0.070	0.081	0.048	0.015	0.020	0.048	0.048
d(A3,A+)	0.070	0.048	0.081	0.033	0.033	0.081	0.048
d(A4,A+)	0.094	0.081	0.081	0.033	0.044	0.081	0.108
d(A5,A+)	0.070	0.081	0.078	0.033	0.044	0.081	0.108
d(A6,A+)	0.042	0.048	0.081	0.033	0.044	0.048	0.081

Table 4: Options intervals from the anti-ideal solution

Distance	*C1*	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*
d(A1,A-)	0.085	0.034	0.034	0.033	0.026	0.101	0.120
d(A2,A-)	0.055	0.071	0.098	0.044	0.040	0.081	0.098
d(A3,A-)	0.055	0.098	0.064	0.033	0.026	0.048	0.098
d(A4,A-)	0.030	0.064	0.064	0.033	0.014	0.048	0.034
d(A5,A-)	0.055	0.064	0.034	0.033	0.014	0.048	0.034
d(A6,A-)	0.085	0.098	0.064	0.033	0.014	0.081	0.064

8. The prioritization of options is based on the magnitude of the similarity index which is shown in Figure 1.

Fuzzy Analytic Hierarchy Process (F. AHP)

Fuzzy Analytic Hierarchy Process is one of the multiple decision making methods. This method was suggested by an Iraqi name Saaty in 1970's (Saaty, 1980). This method analyzes the issues like the human brain. The hierarchical analysis method helps decision makers to set priorities based on their goals, knowledge, and experience so that their feelings and judgements are fully considered. In order to solve the decision problems in this method, we must define and explain the problem with precision and with all the details and show the details in a hierarchical structure.

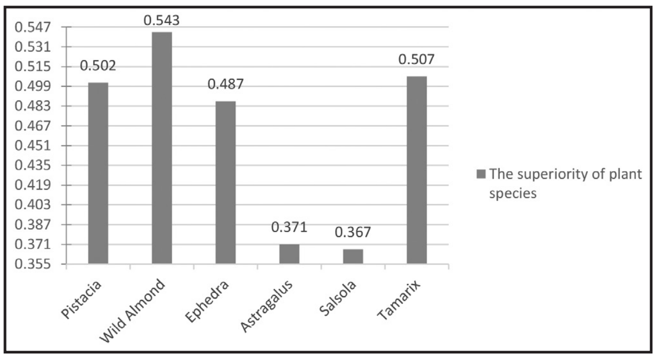

Figure 1: Vegetation species scheme for planting superior plants in the Sarcheshmeh Mine using Fuzzy TOPSIS method.

The algorithm of this method is as follows (Momeni, 2009):

1. Draw a hierarchical structure.
2. The formation of the relative pair comparison matrix which is shown in Table 5.
3. Determining the relative weights which are respectively observed in subsequent formulas and the result is shown in Table 2.

$$S_i = \sum_{j=1}^{n} M_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} \quad (8)$$

$\otimes$ is Fuzzy multiplication, $\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}$ is sum of columns of fuzzy sum of row numbers and $\sum_{j=1}^{n} M_{gi}^{j}$ is fuzzy set of numbers in each row.

$$V(M_2 \geq M_1) = \begin{cases} 1 & \text{If } m_2 \geq m_1 \\ 0 & \text{If } L_1 \geq U_2 \\ \dfrac{L_1 - U_2}{(m_2 - U_2) - (m_1 - L_1)} & \text{Otherwise} \end{cases} \quad (9)$$

$V(M_2 \geq M_1)$ is magnitude of M_2 (first S) compared to M_1 (second S)

Table 5: Pair comparison matrix of criteria in F. AHP method

	C1			*C2*			*C3*			*C4*			*C5*			*C6*			*C7*		
C1	1.0	1.0	1.0	0.6	0.8	1.3	0.6	0.8	1.3	0.7	1.4	3.0	1.0	2.3	4.5	0.6	0.8	1.3	0.6	0.8	1.3
C2	0.8	1.3	1.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.8	3.0	1.4	3.0	4.5	1.0	1.0	1.0	1.0	1.0	1.0
C3	0.8	1.3	1.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.8	3.0	1.4	3.0	4.5	1.0	1.0	1.0	1.0	1.0	1.0
C4	0.3	0.7	1.4	0.3	0.6	1.0	0.3	0.6	1.0	1.0	1.0	1.0	0.6	1.7	3.5	0.3	0.6	1.0	0.3	0.6	1.0
C5	0.2	0.4	1.0	0.2	0.3	0.7	0.2	0.3	0.7	0.3	0.6	1.7	1.0	1.0	1.0	0.2	0.3	0.7	0.2	0.3	0.7
C6	0.8	1.3	1.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.8	3.0	1.4	3.0	4.5	1.0	1.0	1.0	1.0	1.0	1.0
C7	0.8	1.3	1.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.8	3.0	1.4	3.0	4.5	1.0	1.0	1.0	1.0	1.0	1.0

$$d'(A_1) = \min V (S_i \geq S_k) \quad (10)$$

$d'(A_1)$ is non-normalized weight (minimum number of each row according to formula (11) which is obtained by minimizing the relative weights in each row which are normalized using formula (11) and the weights of each criterion are listed in Table 2.

$$W' = (d' (A_1), d' (A_2), \ldots, d' (A_n))^T \quad (11)$$

Each of the weights is normalized by dividing by the sum of the columns of minimums and then the weight of the criteria is obtained.

4. Determining the final weight of each option and prioritizing (in the case of comparing options according to the weight of the above mentioned criteria).

Table 6: Final weights of the criteria

Weight	*Normalize*	*Minimum*
S1	0.146	0.869
S2	0.168	1.000
S3	0.168	1.000
S4	0.114	0.679
S5	0.068	0.404
S6	0.168	1.000
S7	0.168	1.000

Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) Method

Since the goal of this paper is to introduce and apply a PROMETHEE method in the field of the reclamation of open pit mines, in the following, steps of the PROMETHEE method and its application for selection of plant species in the case study is presented. Halouani et al. (2009) said that PROMETHEE method including PROMETHEE-I partial ranking and PROMETHEE-II full ranking, were improved by Brans and Vincke (1985). This method used in the analysis of multi-criteria issues is conceptually and practically simpler in comparison with other methods (Albadavi et al., 2007). In PROMETHEE method, the ranking of options is based on paired comparisons. This method is one of the multi-criteria decision-making methods (Mohaghar and Mostafavi, 2008).

This method is used to evaluate and prioritize discrete options and selecting the best option based on several criteria (with different measurement scales) (Chou et al., 2004). When using PROMETHEE method, there is a limit to compensate the weakness of a benchmark or potency of other criterion and therefore an ideal option must obtain the minimum of all criteria. Additionally, the PROMETHEE method can easily apply criteria with different measurement scales (without the need to match the scale of criteria) and depending on the information and the standard scale, it defines separate six functions; therefore multi-criteria decision making in which criteria usually have different measurements, is a strong point for the decision maker.

Selection of Plant Species Based on Primary and Secondary Factors (Criteria) Using PROMETHEE Method

Because of the conditions in the area and distance from the city and that in all cases the reuse of the mined lands vegetation was a necessary item for the implementation of the reclamation plan in research on the reclamation of the Sarcheshmeh mine, the type of reuse was based on plantation (Osanloo and Parsaei, 2004).

Climate

Rafsanjan has cold and warm winters and dry summers and is in a desert region with a moderate dry climate with an average rainfall of 91 mm. The average relative humidity of the mine station during the current statistical period is 32%. The annual temperature variation in this area is –22 to +32 °C. The plants should be adapted to these atmospheric conditions (Alavi et al., 2014).

Quality of the Soil

According to the experiments conducted in the area, soil acidity is high due to the presence of pyrite. The amount of copper, lead, molybdenum and sulphate exceeds the standard value. Acid-compatible plants absorb these material and prevent them from reaching the surrounding areas (Alavi et al., 2014).

Considering the main factors and adaptation of different species of plants to these conditions in the Sarcheshmeh copper complex in Kerman, six types of vegetation were selected and adapted to these conditions: pistacia (A), wild almond (B), ephedra (C), astragalus (D), salsola (E) and tamarix (F). Then according to the seven criteria of the outlook (C1), resistance to disease and insects (C2), growth type and potency (C3), access to plant species (C4), economic efficiency (C5), soil and water supply conservation (C6), and contamination avoidance (C7), most proper option is chosen with regard to PROMETHEE method.

The performance values of the qualitative criteria are obtained using experts' opinions and the five-point Likert scale method as shown in Table 7.

Table 7: The conversion of the qualitative significance into certain quantitative figures by the five-point Likert scale

Language variables	*Numerical values*
Very low	1
Low	2
Average	3
High	4
Very high	5

Source: Pouya et al., 2013

Decision makers are asked to express their decision regarding the evaluation of options according to the criteria and complete the questionnaires according to the qualitative criterion in accordance with the above mentioned table.

1. Weight vector (0 to 1) is calculated by Fuzzy AHP from the questionnaire in Table 8 and based on formulas (8) to (11), which is shown as follows.

2. Formation of evaluation table: The matrix for evaluating options with regard to the criteria is made up by questionnaires filled in by involved experts. The evaluation table is the starting point of the PROMETHEE method which options in this table are evaluated according to different criteria that are shown in Table 9 (Macharis et al., 2007).

3. Calculating the priority function: When comparing two options $A \in b$ and a, comparisons should be made based on a preference. In PROMETHEE methods, the preference function of each criterion is often determined by the nature of each criterion and decision-maker's perspective (Albadavi et al., 2007). The preference function converts the difference between the values of the two options in a special criterion to the degree of preference that changes from 0 to 1 (Bogdanovic et al., 2012).

$$Pj(a, b) = Fj[dj(a, b)], \quad a,b \in A \tag{12}$$

$$dj(a, b) = fj(a) - fj(b) \tag{13}$$

$$0 \leq Pj(a, b) \leq 1 \tag{14}$$

In which Pj for option a is calculated on option b, which is a function of deviation between $fj(a)$ and $fj(b)$ that is put into Table 10. ($fj(a)$) is criteria value in option a, which exists in options evaluation decision making matrix in Table 9. The basis of the PROMETHEE method is the paired comparison. In this case, the numerical difference between options in each of the criteria is taken into account, so that the decision maker assigns a little preference to the better options for the small differences. If the difference is trivial, the two options are assumed the same criterion-wise, and if the differences are notable, higher score is assigned for the best option.

The paired comparison matrix of the options is prepared by comparing two or more options with respect to each other and to each criterion. In this paper, since all criteria are positive, bigger numbers ($fj(a)$) are set to 1 in comparing two or more options, and set to 0 for smaller and equal numbers ($fj(b)$) (Safari et al., 2012) and $fj(a) - fj(b)$ are shown as Pj in Table 10.

4. Calculation of the overall priority function: in the next step, the options priority matrix is formed in relation to each other for all criteria according to the weight of the criteria, which ultimately results in a cumulative preferential index that is shown in Table 11.

$$\pi(a, b) = \sum_{j=1}^{k} P_j(a, b)\, W_j \tag{15}$$

where $\pi(a, b)$ is sum of $P(a, b)$, for each criterion and W_j is weight related to j, the bigger it is, option a is preferred more (Bogdanovic et al., 2012).

5. Calculation of positive and negative flows

In the next step the positive flow (output flow) is calculated as follows (Brans and Vincke, 1985):

Table 8: Questionnaire of the importance of criteria in relation to each other with consideration of purpose

Criterion/Importance	*Very low*	*Low*	*Average*	*High*	*Very high*
Area landscape				*	
Resistance to disease and insects					*
Growth type and potency					*
Availability of plant species			*		
Economic efficiency		*			
Soil and water supply conservation					*
Pollution avoidance					*

Table 9: Options evaluation matrix

C7	*C6*	*C5*	*C4*	*C3*	*C2*	*C1*	
5	4	3	4	2	2	4	A
4	4	4	5	4	3	3	B
4	3	3	4	3	4	3	C
2	3	2	4	3	3	2	D
2	3	2	1	2	3	3	E
3	4	2	4	3	4	4	F

C1 = 0.146, C2 = 0.168, C3 = 0.168, C4 = 0.114, C5 = 0.068, C6 = 0.168, C7 = 0.168

$$\Phi^{+}(a) = \frac{1}{n-1}\sum_{x \in A} \pi(a, x) \tag{16}$$

where the priority and potency of option a in relation with $n - 1$ shows other options. Biggest $\Phi^{+}(a)$ is the best option (Omidi et al., 2011).

Negative priority flow (incoming flow), also is resulted as follows (Brans and Vincke, 1985):

$$\Phi^{-}(a) = \frac{1}{n-1}\sum_{x \in A} \pi(x, a) \tag{17}$$

This flow shows that how $n - 1$ in other options is prior to other options. In fact, this flow is option a weakness. The smallest $\Phi^{-}(a)$ is the best option (Omidi et al., 2011).

Preferred matrix of the options in which the original diameter is zero and the numbers above the matrix's main diameter include the upper numbers of the cumulative preferential index and the upper numbers of the matrix diameter, include the lower numbers of the cumulative preferential index are shown in Table 12. Thus, by having and evaluating two flows of $\Phi^{+}(a)$ and $\Phi^{-}(a)$, a trivial ranking can be achieved (PROMETHEE I ranking) (Omidi et al., 2011). The problem of this method is shown here, as in Figure 2 when comparing

Table 10: Pairs comparison matrix options (Preference function)

C7	*C6*	*C5*	*C4*	*C3*	*C2*	*C1*	
1	0	0	0	0	0	1	A-B
0	0	1	1	1	1	0	B-A
1	1	0	0	0	0	1	A-C
0	0	0	0	1	1	0	C-A
1	1	1	0	0	0	1	A-D
0	0	0	0	1	1	0	D-A
1	1	1	0	0	0	1	A-E
0	0	0	0	0	1	0	E-A
1	0	1	0	0	0	0	A-F
0	0	0	0	1	1	0	F-A
0	1	1	1	1	0	0	B-C
0	0	0	0	0	1	0	C-B
1	1	1	1	1	0	1	B-D
0	0	0	0	0	0	0	D-B
1	1	1	1	1	0	0	B-E
0	0	0	0	0	0	0	E-B
1	0	1	1	1	0	0	B-F
0	0	0	0	0	1	1	F-B
1	0	1	0	0	1	1	C-D
0	0	0	0	0	0	0	D-C
1	0	1	0	1	1	0	C-E
0	0	0	0	0	0	0	E-C
1	0	1	0	0	0	0	C-F
0	1	0	0	0	0	1	F-C
0	0	0	0	1	0	0	D-E
0	0	0	0	0	0	1	E-D
0	0	0	0	0	0	0	D-F
1	1	0	0	0	1	1	F-D
0	0	0	0	0	0	0	E-F
1	1	0	0	1	1	1	F-E

Table 11: The overall priority matrix of options relative to each other for all criteria

Cumulative preferential index	*C7*	*C6*	*C5*	*C4*	*C3*	*C2*	*C1*	*Criterion*
	0.168	*0.168*	*0.068*	*0.114*	*0.168*	*0.168*	*0.146*	*Criteria importance coefficients*
0.314	0.168	0	0	0	0	0	0.146	A-B
0.518	0	0	0.068	0.114	0.168	0.168	0	B-A
0.482	0.168	0.168	0	0	0	0	0.146	A-C
0.336	0	0	0	0	0.168	0.168	0	C-A
0.55	0.168	0.168	0.068	0	0	0	0.146	A-D
0.336	0	0	0	0	0.168	0.168	0	D-A
0.55	0.168	0.168	0.068	0	0	0	0.146	A-E
0.168	0	0	0	0	0	0.168	0	E-A
0.236	0.168	0	0.068	0	0	0	0	A-F
0.336	0	0	0	0	0.168	0.168	0	F-A
0.518	0	0.168	0.068	0.114	0.168	0	0	B-C
0.168	0	0	0	0	0	0.168	0	C-B
0.832	0.168	0.168	0.068	0.114	0.168	0	0.146	B-D
0	0	0	0	0	0	0	0	D-B
0.686	0.168	0.168	0.068	0.114	0.168	0	0	B-E
0	0	0	0	0	0	0	0	E-B
0.518	0.168	0	0.068	0.114	0.168	0	0	B-F
0.314	0	0	0	0	0	0.168	0.146	F-B
0.55	0.168	0	0.068	0	0	0.168	0.146	C-D
0	0	0	0	0	0	0	0	D-C
0.572	0.168	0	0.068	0	0.168	0.168	0	C-E
0	0	0	0	0	0	0	0	E-C
0.236	0.168	0	0.068	0	0	0	0	C-F
0.314	0	0.168	0	0	0	0	0.146	F-C
0.168	0	0	0	0	0.168	0	0	D-E
0.146	0	0	0	0	0	0	0.146	E-D
0	0	0	0	0	0	0	0	D-F
0.65	0.168	0.168	0	0	0	0.168	0.146	F-D
0	0	0	0	0	0	0	0	E-F
0.818	0.168	0.168	0	0	0.168	0.168	0.146	F-E

Table 12: Options preference matrix

Outgoing current Φ^+	*F*	*E*	*D*	*C*	*B*	*A*	
2.132	0.236	0.55	0.55	0.482	0.314	0	A
3.072	0.518	0.686	0.832	0.518	0	0.518	B
1.862	0.236	0.572	0.55	0	0.168	0.336	C
0.504	0	0.168	0	0	0	0.336	D
0.314	0	0	0.146	0	0	0.168	E
2.432	0	0.818	0.65	0.314	0.314	0.336	F
	0.99	**2.794**	**2.728**	**1.314**	**0.796**	**1.694**	Incoming current Φ^-

C and A, the positive flow of C is less (worse) than A, while its negative flow is less (better) in relation to A, and this method cannot show clearly the priority of C and A comparatively.

6. Net flow calculation: For complete ranking of the options the net flow of ranking for each option must be defined (PROMETHEE II ranking) which is shown in Table 13 and Figure 3. This flow is the result of the balancing of positive and negative ranking streams. The higher net flow indicates the preferred option (Omidi et al., 2011). To calculate net flow, the following equation is used which is a positive and negative flow difference (Brans and Vincke, 1985).

$$\Phi(a) = \Phi^{+}(a) - \Phi^{-}(a) \tag{18}$$

Table 13: PROMETHEE II flows and general ranking

	Grade	*(Φ⁺)-(Φ⁻)*	*Φ⁻*	*Φ⁺*	*Option*
Pistacia	**4**	**0.44**	1.694	2.132	A
Almond	**1**	**2.28**	0.796	3.072	B
Ephedra	3	0.55	1.314	1.862	C
Astragalus	**5**	**-2.22**	2.728	0.504	D
Salsola	**6**	**-2.48**	2.794	0.314	E
Tamarix	**2**	**1.44**	0.99	2.432	F

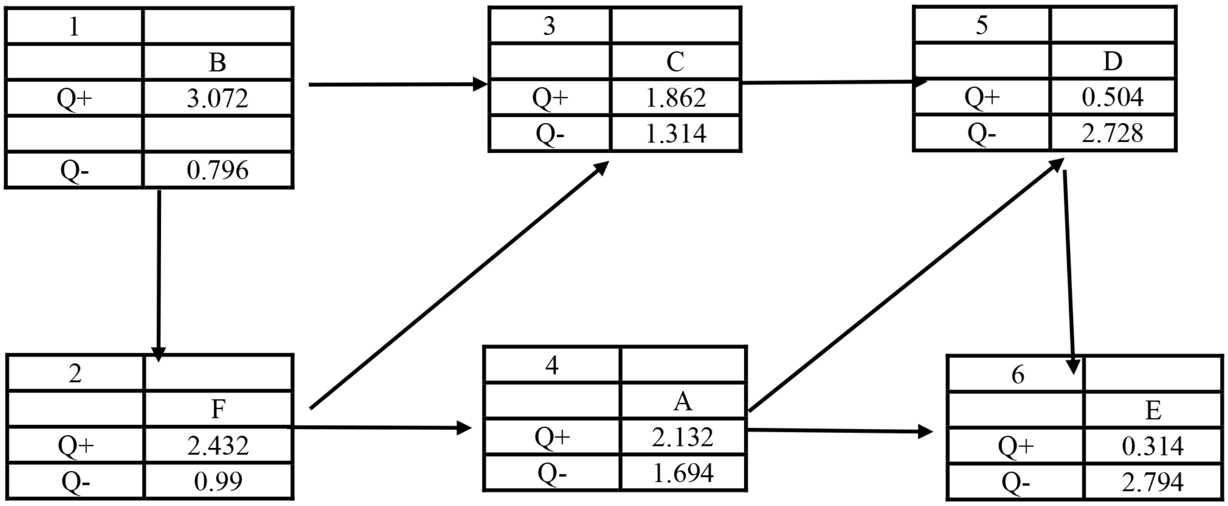

Figure 2: PROMETHEE I trivial ranking.

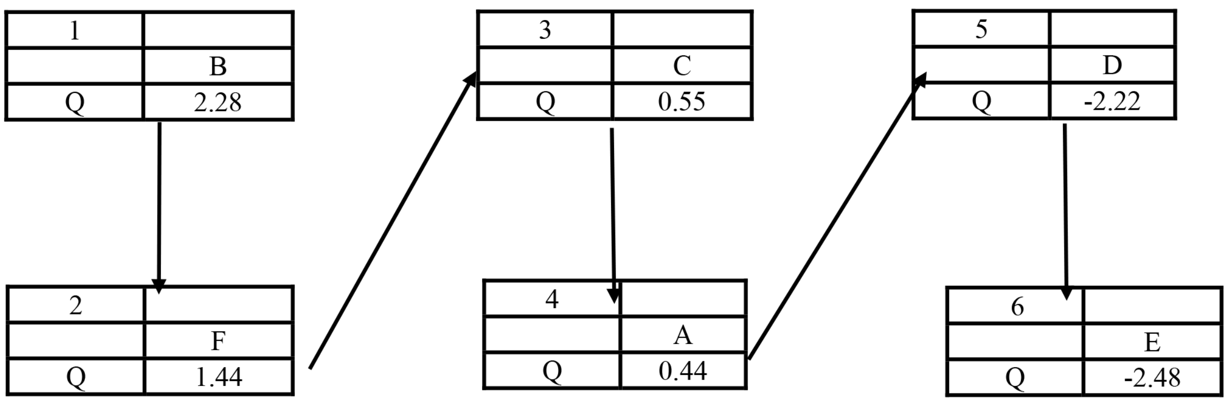

Figure 3: PROMETHEE II complete ranking.

Conclusions

In this paper, the decision making method for selecting the appropriate plant species for the reclamation of Sarcheshmeh copper mine is discussed. Selecting the method of regeneration and the type of plant species is one of the most important parts of the mining project. The Fuzzy AHP method was used to calculate weights, while the PROMETHEE method was used to rank the options. Among the important advantages of PROMETHEE method, are the clear effect of each of the criteria and their weights on the results, the high efficiency of this algorithm while being simple, clarity and permanence and being based on the importance of the difference in the performance of the two results. This method can perform the evaluation process on a limited set of limited alternatives as a complete or partial ranking.

As it is seen, the first and second selection of plant species in both PROMETHEE and Fuzzy TOPSIS are almond and tamarix plant species. The point in the Fuzzy TOPSIS method is that the weighting of the criteria in the past research has been used to normalize the numbers from 1 to 9 and the result of the present study is that the weight of the criteria used the hierarchical analysis method that is more complete and logical. However, no significant difference was found in overall outcomes. Finally, in the Fuzzy TOPSIS method, the preference of the species are as follows: Wild almond (0.543), tamarix (0.507), pistacia (0.502), ephedra (0.487), astragalus (0.371), salsola (0.367) and in PROMETHEE method as follows: Wild almond (2.28), tamarix (1.44), ephedra (0.55), pistacia (0.44), astragalus (–2.22), salsola (–2.48).

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