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ARASH EBRAHIMABADI*, IRAJ ALAVI**

PLANT TYPE SELECTION FOR RECLAMATION OF SARCHESHMEH COPPER MINE USING FUZZY-TOPSIS APPROACH

WYBÓR GATUNKÓW ROŚLIN DO WYKORZYSTANIA W PROJEKCIE REKULTYWACJI TERENÓW KOPALNI MIEDZI SARCHESHMEH Z WYKORZYSTANIEM METOD LOGIKI ROZMYTEJ TOPSIS

Plant species selection is a multi-criteria evaluation decision and has a strategic importance for many companies. The conventional methods for plant species selection are inadequate for dealing with the imprecise or vague nature of linguistic assessment. To overcome this difficulty, fuzzy multi-criteria decision-making methods are proposed. The aim of this study is to use the fuzzy technique for order preference by similarity to ideal solution (F.TOPSIS) methods for the selection of plant species in mine reclamation plan. Plant type selection and planting to protect the environment and the reclamation of the mine are some of the most important solutions. Therefore, the objective of the current research study is to choose the proper plant types for reclamation of Sarcheshmeh Copper Mine using Fuzzy-topsis method. In this regard, primarily, surrounding area of Sarcheshmeh copper mine, one of the world's 10 biggest copper mine which is located near Kerman city of Iran, are surveyed, to choose the best plant type for reclamation of disturbance area. With this respect, based on reclamation plan, primary criteria were consisted of kinds of post mining land use, climate, and nature of soil. Comparison matrixes were then obtained based on experts' opinion and plant types were subsequently prioritized using the Fuzzy Topsis method. Secondary factors considered through the analysis were as follows: perspective of the region, resistance against disease and insects, strength and method of growth, availability to plant type, economic efficiency, protection of soil, storing water, and prevention of pollution. Finally, suitable plant types in the mining perimeter were prioritized as: Amygdalus scoparia, Tamarix, Pistachio Wild, Ephedra, Astragalus, Salsola, respectively.

Keywords: mine reclamation, plant type selection, Sarcheshmeh Copper Mine, Fuzzy TOPSIS

Wybór gatunków roślin jest decyzją podejmowaną w oparciu o wiele kryteriów i stanowi poważne wyzwanie strategiczne dla wielu firm. Konwencjonalne metody wyboru gatunków roślin okazują się niewystarczające w przypadku nieprecyzyjnej oceny i nie w pełni zdefiniowanych określeń językowych. W celu

* DEPARTMENT OF MINING ENGINEERING, FACULTY OF ENGINEERING, QAEMSHAHR BRANCH, ISLAMIC AZAD UNIVERSITY, QAEMSHAHR, IRAN, E-mail: Arash.xer@gmail.com (CORRESPONDING AUTHOR).

** DEPARTMENT OF MINING ENGINEERING, SCIENCE AND RESEARCH BRANCH, ISLAMIC AZAD UNIVERSITY, TEHRAN, IRAN, E-mail: iraj_alavi@yahoo.com

przezwyciężenia tych trudności, zaproponowano wielo-kryterialną metodę decyzyjną wykorzystującą logikę rozmytą. Celem tego opracowania jest ukazanie zastosowania podejścia rozmytego do uzyskania kolejnych przybliżeń do rozwiązania idealnego (F.TOPSIS) przy wyborze odpowiednich gatunków roślin do użycia w projekcie rekultywacji terenów kopalni. Wybór gatunków roślin i ich kultywacja dla zapewnienia ochrony środowiska i projektu rekultywacji terenu pogórniczego to bardzo ważne zagadnienia. Głównym celem obecnego studium jest wybór odpowiednich gatunków roślin do wykorzystania projekcie rekultywacji terenów kopalni miedzi Sarcheshmeh z wykorzystaniem metod logiki rozmytej TOPSIS. W pierwszym rzędzie przeprowadzono badania gruntów wokół kopalni miedzi Sarchesmeh, w pobliżu miejscowości Kerman w Iranie (jednej z dziesięciu największych na świecie kopalni miedzi) w celu wyboru najlepszych typów roślin do wykorzystania do rekultywacji naruszonych działalnością górniczą terenów. Określono podstawowe kryteria wyboru, biorąc pod uwagę plan rekultywacji: sposoby wykorzystania terenu, klimat oraz rodzaje gleb. Otrzymano macierze porównawcze uzyskane na podstawie opinii ekspertów, następnie dokonano określenia priorytetów dla poszczególnych roślin przy pomocy metody TOPSIS, wykorzystującej logikę rozmytą. W analizie uwzględniono następujące czynniki drugorzędne: perspektywy dla regionu, odporność na choroby i owady szkodniki, wytrzymałość i sposób uprawy, dostępność danego gatunku roślin, wydajność ekonomiczna, ochrona gleb, zdolność zatrzymywania wody, zapobieganie zanieczyszczeniom. W końcowym etapie dokonano wyboru najkorzystniejszych dla danego terenu górniczego gatunków roślin, podając kolejno: *Amygdalus scoparia*, *Tamarix, Pistachio Wild, Ephedra, Astragalus, Salsola*.

Słowa kluczowe: rekultywacja terenów kopalni, wybór gatunków roślin, kopalnia miedzi Sarchesmeh, metoda logiki rozmytej TOPSIS

1. Introduction

The restoration of plant covering in the destructed areas could have a prodigious influence on decreasing erosion and destruction of areas. Plants play a major role in physical and chemical changes in the soil (Tavili, 2010). Today, one of the issues highly regarded for any planning such as mine planning, is the sustainability and environmental issues. It is obvious that any mining practice can affect the surrounded area; therefore, mine reclamation plan needs to be conducted to preserve the mined environment and should be considered as a major task in mine closure phase. Mine reclamation is the process of restoring land that has been mined to a natural or economically usable purpose. Although the process of mine reclamation occurs once mining is completed; the preparation and planning of mine reclamation activities occur prior to a mine being permitted or started. Mine reclamation creates useful landscapes that meet a variety of goals ranging from the restoration of productive ecosystems to the creation of industrial and municipal resources. Mine reclamation is a regular part of modern mining practices. From among reclamation approaches, planting and forestry are the most desirable choices for the reclamation of mined lands, leading to restore pre-mining environment and condition. Moreover, an appropriate reclamation plan can provide convenient post-mining land use (Osanloo & Parsaei, 2004; Soltanmohammadi et al., 2010). A proper implementation of mine reclamation plan is remarkable from planting point of view, leading to preparing suitable condition for plant growing and environment protection (Xia et al., 2007). There is another expression versus reclamation; called “rehabilitation”. In rehabilitation process, it is endeavored to restore indigenous vegetation using locally sourced types and specimens, if possible. In this respect, further attempts should be spent to restore ecosystem functioning rather than merely replacing plants to replicate the pre-mining environment (Redente & Baker, 1996). Due to specified plant types and certain indigenous vegetation in the rehabilitation plan, plant species selection is not as important as in the reclamation process. Mixtures of plant types including stoloniferous and bunch grasses vary from site to other sites and each site has its own conditions. Hence, site-specific advices are necessary before any decision-making on which plant types to use for reclamation. In the majority of successful cases, plant type selection is depend on parameters such as appropriate species adapting with the existing land condition, proper soil preparation, correct liming and fertilization preferably using organic fertilizers, irrigation and supplementary seeding where necessary. Thus, suitable plants and cultivation method selection for re-vegetation are essential issues in the reclamation process (Redente & Baker, 1996). In addition, Belsky and Canham (1994) demonstrated that properties and nutritious material resources in the soil are intensively depended on plant covering.

Mining operations have adverse impacts on the environment though novel mining methods with new technologies are able to reduce the impacts of mining in the territory. Nevertheless, reclamation plan has to be accomplished properly to achieve sustainable results. Mine reclamation is an important subject due to two environmental aspects, including (Xia et al., 2007):

i) Significant decrease in pollution of disturbance area and preparing the mined land to keep species life cycle.
ii) Providing sustainable conditions to further activities and post-mining land use.

As per the selected plants, Haque et al. (2009) stated that chosen species should be resistant against the adverse conditions of mine waste and mining regional soil. For instance, Alavi et al. (2011a) demonstrated that the best pH for plant growth assumed to be 6.5 to 7.5.

In a simple statement, plant species selection, suitability for various subjective criteria, and the weights of the criteria are usually expressed in linguistic terms. In this regard, the fuzzy set theory has been used to establish an ill-defined multiple criteria decision-making problems in order to efficiently resolve the ambiguity frequently arising in available information and do more justice to the essential fuzziness in human judgment and preference (Liang, 1999). There are many attempts to apply multi-criteria decision-making approaches to mining issues; for instance, Nourali et al. (2012) mentioned some approaches to mining method selection. Regarding mine reclamation and environmental improvements, Coppin and Bradshaw (1982); Monterroso et al. (1998); Chen et al. (1998); Askenasy and Brandt (1998); Howat (2000); Maiti and Ghose (2005); Tafi et al. (2006) and Carrick and Kruger (2007) have evaluated the factors limiting plant growth on mined soils and mentioned the most serious soil limitations. Cairns (1982); Alexander (1996); Wisconsin (2000); Coppin and Box (1999); Errington (2001); Paschke et al. (2003); Stellin et al. (2005) have studied the planting impact on the mining soil. Soltanmohammadi et al. (2010) have used combination of group versions of AHP and TOPSIS techniques to determine a preference ranking list for possible post-mining land uses of a hypothetical mined land based on the Mined Land Suitability Analysis framework. Bangian and Osanloo (2008) have selected proper plant species for Sungun Copper mine reclamation by traditional AHP method. Alavi et al. (2011b) have selected proper plant species for Sarcheshmeh Copper mine reclamation by fuzzy AHP method. Alavi and Alinejad (2011) have selected proper plant species for Sungun Copper mine reclamation by Fuzzy AHP method and Fuzzy Topsis method, together. In this research study, the proper plant selection was performed for Sarcheshmeh Copper mine of Iran using Fuzzy-Topsis approach.

2. Materials and methods

2.1. Importance of selected plant species in the reclamation of the mine

Reclamation of the mine is a necessary step in order to post-mining land use, plantership and preparing green space for the region. Thus, plant type selection is one of the major steps to gain the goals of the reclamation plan. Superior plant type selection in every reclamation program has many advantages such as: health protection and environment restoring, perspective of the region, economic benefits, welfare of life for local people, pollution reduction of soil, water and air, underground water supply, prevent of soil erosion (Bangian & Osanloo, 2008).

2.1.1. Factors affecting on selection of plant species

There are two groups of factors affecting on selection of plant species (Osanloo, 2001). These factors are as follows:

A) Primary factors:

This group of factors consists of type of post mining land use, zone climate, and nature of soil, respectively. Initial selection of plant types studied for mine reclamation must be carried out in accordance to the primary factors. The sub-groups of each factors are cited as below.

The issues to be considered for post mining land use include: land replication to the initial state, agricultural activities, afforest and wildlife, landscape beautification and tourist attractions, and residential purposes. Plant species are expected to be compatible with each aforementioned issue. As a consequence in this step, the species coordinated with the type of post mining land use are chosen.

These plant types are then examined according to the next primary factors; zone climate or regional climate conditions. At this stage, among the selected types from the first step, the types adapted to local climate conditions are selected, and other alternatives are rejected. In this respect, the issues to be considered are: ground slope and condition, lighting and sunlight, weather, moisture, temperature, wind, and air pollutants in the area.

Afterward, zone soil quality is also the third element for the primary factors through the selection process. After this stage, some alternatives are rejected. The properties of regional soil to be noticed are: acidity or alkalinity, salinity, heavy metals, and organic materials of the soil.

B) Secondary factors:

After some appropriate species were chosen through the previous step, the selection process continues in accordance with secondary factors, including (Alavi et al., 2011b):

C1) Perspective of the region, C2) Resistance against diseases and insects, C3) Rate and method of growth, C4) Availability to plant type, C5) Economic efficiency, C6) Protection of soil and storing water, C7) Prevention from pollution.

Finally, after investigating the secondary factors, the most proper plant species are selected for reclamation of mined areas.

3. Fuzzy sets

In order to deal with vagueness of human thought, Zadeh (1965) first introduced the fuzzy set theory. A fuzzy set is a class of objects with a continuum of grades of membership. Such a set is characterized by a membership function which assigns to each object a grade of membership ranging between zero and one (Zadeh, 1965). A fuzzy set is an extension of a crisp set. Crisp sets only allow full membership or non-membership at all, whereas fuzzy sets allow partial membership. In other words, an element may partially belong to a fuzzy set (Ertuğrul & Karakaşoğlu, 2006). Fuzzy sets and fuzzy logic are powerful mathematical tools for modeling: uncertain systems in industry, nature and humanity; and facilitators for commonsense reasoning in decision-making in the absence of complete and precise information. Their role is significant when applied to complex phenomena not easily described by traditional mathematical methods, especially when the goal is to find a good approximate solution (Bojadziev & Bojadziev, 1998). Fuzzy sets theory providing a more widely frame than classic sets theory, has been contributing to capability of reflecting real world (Ertuğrul & Tuş, 2007). Modeling using fuzzy sets has proven to be an effective way for formulating decision problems where the information available is subjective and imprecise (Zimmermann, 1992). Triangular fuzzy numbers can be defined as a triplet (l, m, u). The parameters l, m and u. respectively, indicate the smallest possible value, the most promising value, and the largest possible value that describe a fuzzy event (Ertuğrul & Karakaşoğlu 2007).

3.1. Linguistic variable

A linguistic variable is a variable whose values are words or sentences in a natural or artificial language (Zadeh, 1975). As an illustration, age is a linguistic variable if its values are assumed to be the fuzzy variables labeled young, not young, very young, not very young, etc. rather than the numbers 0, 1, 2, 3.. (Bellman & Zadeh, 1977). The concept of a linguistic variable provides a means of approximate characterization of phenomena which are too complex or too ill-defined to be amenable to description in conventional quantitative terms. The main applications of the linguistic approach lie in the realm of humanistic systems-especially in the fields of artificial intelligence, linguistics, human decision processes, pattern recognition, psychology, law, medical diagnosis, information retrieval, economics and related areas (Zadeh, 1975).

3.2. Fuzzy numbers

A fuzzy number $\widetilde{M}$ is a convex normalized fuzzy set $\widetilde{M}$ of the real line R such that (Zimmermann, 1992):

- It exists such that one $x_0 \in \mathrm{R}$ with $\mu_{\widetilde{M}}(x_0) = 1$ (x_0 is called mean value of $\widetilde{M}$)
- $\mu_{\widetilde{M}}(x_0)$ is piecewise continuous.

It is possible to use different fuzzy numbers according to the situation. In applications it is often convenient to work with triangular fuzzy numbers (TFNs) because of their computational simplicity, and they are useful in promoting representation and information processing in a fuzzy environment. In this study TFNs are adopted in the fuzzy AHP and fuzzy TOPSIS methods. Triangular fuzzy numbers can be defined as a triplet (l, m, u). The parameters l, m and u. respectively, indicate the smallest possible value, the most promising value, and the largest possible value that describe a fuzzy event. A triangular fuzzy number $\tilde{M}$ is shown in Fig. 1 (Deng, 1999). There are various operations on triangular fuzzy numbers. But here, only important operations used in this study are illustrated. If we define, two positive triangular fuzzy numbers ($l1$, $m1$, $u1$) and ($l2$, $m2$, $u2$) then: (K is a positive real number)

$$(l1, m1, u1) + (l2, m2, u2) = (l1 + l2, m1 + m2, u1 + u2) \tag{1}$$

$$(l1, m1, u1) \cdot (l2, m2, u2) = (l1 \cdot l2, m1 \cdot m2, u1 \cdot u2) \tag{2}$$

$$(l1, m1, u1)^{-1} \approx (1/u1, 1/m1, 1/l1) \tag{3}$$

$$(l1, m1, u1) \cdot K = (l1k, m1k, u1k) \tag{4}$$

The distance between two triangular fuzzy numbers can be calculated by vertex method (Chen, 2000):

$$d_v\left(\tilde{m},\tilde{n}\right) = \sqrt{1/3[(l1-l2)^2 + (m1-m2)^2 + (u1-u2)^2]} \tag{5}$$

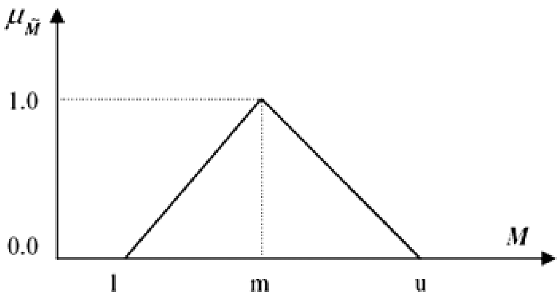

Fig. 1. Triangular fuzzy number

3.3. Fuzzy TOPSIS method

The TOPSIS method was firstly proposed by Hwang and Yoon (1981). The basic concept of this method is that the chosen alternative should have the shortest distance from the positive ideal solution and the farthest distance from negative ideal solution. Positive ideal solution is a solution that maximizes the benefit criteria and minimizes cost criteria, whereas the negative ideal solution maximizes the cost criteria and minimizes the benefit criteria (Wang & Elhag, 2006). In the classical TOPSIS method, the weights of the criteria and the ratings of alternatives are known precisely and crisp values are used in the evaluation process. However, under many conditions crisp data are inadequate to model real-life decision problems. Therefore, the fuzzy TOPSIS method is proposed where the weights of criteria and ratings of alternatives are evaluated by linguistic variables represented by fuzzy numbers to deal with the deficiency in the traditional TOPSIS. In this paper, the extension of TOPSIS method is considered which was proposed by Chen (2000) and Chen et al. (2006). The algorithm of this method can be described as below:

Step 1: First of all, a committee of decision-makers is formed. In a decision committee that has K decision-makers; fuzzy rating of each decision-maker $D_k = (k = 1, 2, ..., K)$ can be represented as triangular fuzzy number $\widetilde{R_K} = ((K = 1, 2, ..., K)$ with membership function $u_{\widetilde{R_K}}(x)$.

Step 2: Then evaluation criteria are determined.

Step 3: After that, appropriate linguistic variables are chosen for evaluating criteria and alternatives.

Step 4: Then the weights of criteria are aggregated (Chen et al, 2006).

If the fuzzy ratings of all decision-makers are described as triangular fuzzy numbers $\widetilde{R_K} = (a_k, b_k, c_k)$, $k = 1, 2, ..., K$, then the aggregated fuzzy rating can be determined as $\widetilde{R} = (a, b, c)$, $k = 1, 2, ..., K$.

Here;
$$a = \min\{a_k\},\ B = \frac{1}{k}\sum_{k=1}^{k} b_k\ ,\ c = \max\{c_k\} \tag{6}$$

If the fuzzy rating and importance weight of the k_{th} decision-maker are $\widetilde{x_{ijk}} = (a_{ijk}, b_{ijk}, c_{ijk})$ and $\widetilde{w_{ijk}} = (w_{jk1}, w_{jk2}, w_{jk3})$, $i = 1, 2, ..., m$; $j = 1, 2, ..., n$ respectively, then the aggregated fuzzy ratings $(\widetilde{x}_{ij})$ of alternatives with respect to each criterion can be found as $(\widetilde{x}_{ij}) = (a_{ij}, b_{ij}, c_{ij})$

Here,
$$a_{ij} = \min\{a_{ijk}\},\ B_{ij} = \frac{1}{k}\sum_{k=1}^{k} b_{ijk}\ ,\ c = \max\{c_{ijk}\} \tag{7}$$

Then the aggregated fuzzy weights $(\widetilde{w}_{ij})$ of each criterion are calculated as: $(\widetilde{w}_{ij}) = (w_{j1}, w_{j2}, w_{j3})$

Here,
$$W_{j1} = \min\{w_{jk1}\},\ w_{j2} = \frac{1}{k}\sum_{k=1}^{k} w_{jk2}\ ,\ w_{j3} = \max\{w_{jk3}\} \tag{8}$$

(Liao & Kao, 2011).

Step 5: Then the fuzzy decision matrix is constructed as:

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix},\quad \tilde{w} = [\tilde{w}_1, \tilde{w}_2, ..., \tilde{w}_n]$$

Here $(\widetilde{x}_{ij}) = (a_{ij}, b_{ij}, c_{ij})$ and $(\widetilde{w}_{ij}) = (w_{j1}, w_{j2}, w_{j3})$; $i = 1, 2, ..., m$; $j = 1, 2, ..., n$ can be approximated by positive triangular fuzzy numbers (Liao & Kao, 2011).

Step 6: After constructing the fuzzy decision matrix, it is normalized. Instead of using complicated normalization formula of classical TOPSIS, the linear scale transformation can be used to transform the various criteria scales into a comparable scale. Therefore, we can obtain the normalized fuzzy decision matrix $\widetilde{R}$ (Chen, 2000).

$$\widetilde{R} = [\widetilde{x}_{ij}]_{m\times n},\ \ i = 1,2,...,m; j = 1,2,...,n$$

Where:

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{cj^{+}}, \frac{b_{ij}}{cj^{+}}, \frac{c_{ij}}{cj^{+}}\right)\ ,\ cj^{+} = \max_j c_{ij} \tag{9}$$

In the above equations $\tilde{r}_{ij}$ is element of normalized matrix, a_{ij} is the first component and cj^{+} is the maximum component of each column

Step 7: Considering the different weight of each criterion, the weighted normalized decision matrix is computed by multiplying the importance weights of evaluation criteria and the values in the normalized fuzzy decision matrix. The weighted normalized decision matrix $\widetilde{V}$ is defined as:

$$\widetilde{V} = [\widetilde{V}_{ij}]_{m\times n}, i = 1,2,...,m; j = 1,2,...,n,\ \widetilde{V}_{ij} = \tilde{r}_{ij\ (.)}\ \widetilde{W}_{ij} \tag{10}$$

Here $\widetilde{W}_j$ represents the importance weight of criterion C_j. According to the weighted normalized fuzzy decision matrix, normalized positive triangular fuzzy numbers can also approximate the elements $\widetilde{V}_{ij}$, $\forall i,j$.

Step 8: Then, the fuzzy positive ideal solution (FPIS, A^{+}) and fuzzy negative ideal solution (FNIS, A^{-}) are determined as (Chen et al., 2006):

$$A^{+} = (\widetilde{V_1}^{+}, \widetilde{V_2}^{+},..., \widetilde{V_n}^{+}) \tag{11}$$

$$A^{-} = (\widetilde{V_1}^{-}, \widetilde{V_2}^{-},..., \widetilde{V_n}^{-}) \tag{12}$$

Where $V_j^{+} = \max_i\{\tilde{v}_{ij3}\}$ is the most ideal in each column, $V_j^{-} = \min_i\{\tilde{v}_{ij1}\}$ is the most anti ideal in each column, $i = 1,2,...,m; j = 1,2,...,n$.

Step 9: Then the distance of each alternative from FPIS and FNIS are calculated as:

$$d_i^{+} = \sqrt{1/3\sum_{j=1}^{n}\left(\tilde{V}_{ij} - V_j^{+}\right)^2} \tag{13}$$

$$d_i^{-} = \sqrt{1/3\sum_{j=1}^{n}\left(\tilde{V}_{ij} - V_j^{-}\right)^2} \tag{14}$$

Where d_i^{+} and d_i^{-} are the distances of each alternative from FPIS and FNIS, respectively.

Step 10: A closeness coefficient of each alternative is defined to rank all possible alternatives. The closeness coefficient represents the distances to the fuzzy positive ideal solution (A^{+}) and fuzzy negative ideal solution (A^{-}) simultaneously. This coefficient can be calculated as below (Alavi & Alinegad, 2011):

$$CC_i = \frac{d^{-}}{d^{-} + d^{+}}\ \ , i = 1,2,...,m \tag{15}$$

Where (CC_i) is the closeness coefficient of each alternative.

Step 11: According to the closeness coefficient, the ranking of the alternatives can be determined. Obviously, according to Eq. (15) an alternative A_i would be closer to FPIS and farther from FNIS as CC_i approaches to 1.

4. Case study

The field study was carried out at Sarcheshmeh copper mine in the province of Kerman located in the south-eastern part of Iran. Longitude, latitude and height from sea level of Sarcheshmeh copper mine are 55° 52’ 20” east, 29° 56’ 40” north and 2620 m, respectively. The mine is one of the world’s 10 biggest copper mine and is located in 65 km southwest far from Rafsanjan city (Bakhshandeh et al., 2010). The mine is known as one of the world’s largest open pit mines and one of the country’s mineral and industrial complexes. The main objective of current research work is to select the proper plant species for reclamation of Sarcheshmeh copper mine with respect to protect the surrounding area from environmental impacts due to mining operations. This is carried out to meet the environmental impacts on local residents, lands and underground waters, beautifying the landscape of the region and preservation of the regional environment.

4.1. Primary factors for plant type selection in Sarcheshmeh copper mine

In this research work, according to the necessary parameters to mine reclamation, investigations are first accomplished regarding the primary factors, as presented below:

1. Type of post mining land use: Considering the situation of the region and being away from the city, planting is the best option for post mining land use.
2. Climate condition: Rafsanjan has cold winters and hot summers. The territory is a desert region with a temperate dry climate and average rainfall of 91 mm per year. According to statistical data from mine stations, the average relative humidity is 38%. The temperature range in the area varies from –22 to +32°C. Desired plants should be compatible with the current climate conditions (Alavi et al., 2011b).
3. Nature of soil: Achieved results from sampling of the regional soil showed that the acidity is very high due to pyrite content. The amount of lead and copper, molybdenum as well as sulfate exceeded standard limits. With regard to the mentioned properties of the soil, plant types are proposed as to consistency and viability against acidic condition. These plant types are expected to absorb pollutant elements, leading to protection of the residential areas (Alavi et al., 2011b).

4.2. Plant type selection based on secondary factors using Fuzzy-Topsis method

As cited before, the TOPSIS method was firstly proposed by Hwang and Yoon (1981). The basic concept of this method is that the chosen alternative should have the shortest distance from the positive ideal solution and the farthest distance from negative ideal solution. Positive ideal solution is a solution that maximizes the benefit criteria and minimizes cost criteria, whereas the negative ideal solution maximizes the cost criteria and minimizes the benefit criteria. The fuzzy TOPSIS method is proposed where the weights of criteria and ratings of alternatives are evaluated by linguistic variables represented by fuzzy numbers to deal with the deficiency in the traditional TOPSIS. Chen (2000) extended the TOPSIS to the fuzzy environment. The algorithm of this method for selecting plant types can be described as follows:

1. Construct the fuzzy decision matrix:

Considering the listed factors and expert's opinions, two questionnaires were prepared. The first questionnaire was about the importance of the criteria toward the goal and the second was about the alternative's importance about the sixth criteria (Protection of soil and storing water), as shown in Table 1 and Table 2. Decision matrix is illustrated in Table 3. Below, the importance coefficient of questionnaire to both qualitative and quantitative is come. Importance of qualitative displaces by quantitative values. Fuzzy numbers are defined as very low [0,1,3], low [1,3,5], medium [3,5,7], high [5,7,9], very high [7,9,10].

TABLE 1

Criteria questionnaire toward the goal

Very high	High	Medium	low	Very low	Importance/criteria
	♣				C1
♣					C2
♣					C3
		♣			C4
			♣		C5
♣					C6
					C7

TABLE 2

Alternatives questionnaire toward C6

Very high	High	Medium	low	Very low	Importance/Alternative In C6
♣					Pistachio
	♣				Amygdalus
		♣			Ephedra
		♣			Astragalus
		♣			Salsola
	♣				Tamarix

TABLE 3

Decision matrix for fuzzy Topsis method

	C1	C2	C3	C4	C5	C6	C7
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

2. Determine criteria weight: Weight vector (0 till 1) is obtained to normalize the importance coefficient that by dividing the fuzzy numbers of importance coefficient on their total accounts.

[0 = 0, 1 = 0.028, 3 = 0.085, 5 = 0.142, 7 = 0.200, 9 = 0.257, 10 = 0.285]

3. Normalize the fuzzy decision matrix: For positive criteria, select the highest number in each column, then all numbers are divided thereon. For negative criteria, select the lowest number for each column and divide on the all number. Since all criteria are positive in this research, the formula is based on positive criteria (using Eq. 9), as shown in Table 4.

TABLE 4

Normalized fuzzy decision matrix

	C1	C2	C3	C4	C5	C6	C7
A1	0.556, 0.778, 1.000	0.111, 0.333, 0.556	0.111, 0.333, 0.556	0.556, 0.778, 1.000	0.333, 0.556, 0.778	0.778, 1.000, 1.111	0.778, 1.000, 1.111
A2	0.333, 0.556, 0.778	0.333, 0.556, 0.778	0.556, 0.778, 1.000	0.778, 1.000, 1.000	0.556, 0.778, 1.000	0.556, 0.778, 1.000	0.556, 0.778, 1.000
A3	0.333, 0.556, 0.778	0.556, 0.778, 1.000	0.333, 0.556, 0.778	0.556, 0.778, 1.000	0.333, 0.556, 0.778	0.333, 0.556, 0.778	0.556, 0.778, 1.000
A4	0.111, 0.333, 0.556	0.333, 0.556, 0.778	0.333, 0.556, 0.778	0.556, 0.778, 1.000	0.111, 0.333, 0.556	0.333, 0.556, 0.778	0.111, 0.333, 0.556
A5	0.333, 0.556, 0.778	0.333, 0.556, 0.778	0.111, 0.333, 0.556	0.556, 0.778, 1.000	0.111, 0.333, 0.556	0.333, 0.556, 0.778	0.111, 0.333, 0.556
A6	0.556, 0.778, 1.000	0.556, 0.778, 1.000	0.333, 0.556, 0.778	0.556, 0.778, 1.000	0.111, 0.333, 0.556	0.556, 0.778, 1.000	0.333, 0.556, 0.778

4. Construct weighted normalized fuzzy decision matrix (using Eq. 10), as shown in Table 5.

TABLE 5

Weighted normalized fuzzy decision matrix

0.079, 0.156, 0.257	0.022, 0.086, 0.158	0.022, 0.086, 0.158	0.047, 0.110, 0.200	0.009, 0.047, 0.110	0.156, 0.257, 0.317	0.156, 0.257, 0.317
0.047, 0.111, 0.200	0.067, 0.143, 0.222	0.111, 0.200, 0.285	0.066, 0.142, 0.222	0.016, 0.066, 0.142	0.111, 0.200, 0.285	0.111, 0.200, 0.285
0.047, 0.111, 0.200	0.111, 0.200, 0.285	0.067, 0.143, 0.222	0.047, 0.110, 0.200	0.009, 0.047, 0.110	0.067, 0.143, 0.222	0.111, 0.200, 0.285
0.016, 0.067, 0.143	0.067, 0.143, 0.222	0.067, 0.143, 0.222	0.047, 0.110, 0.200	0.003, 0.028, 0.079	0.067, 0.143, 0.222	0.022, 0.086, 0.158
0.047, 0.111, 0.200	0.067, 0.143, 0.222	0.0220.086, 0.158	0.047, 0.110, 0.200	0.003, 0.028, 0.079	0.067, 0.143, 0.222	0.022, 0.086, 0.158
0.079, 0.156, 0.257	0.111, 0.200, 0.285	0.067, 0.143, 0.222	0.047, 0.110, 0.200	0.003, 0.028, 0.079	0.111, 0.200, 0.285	0.067, 0.143, 0.222

5. Determine FPIS and FNIS: The fuzzy positive ideal solution (FPIS, A^+) and fuzzy negative ideal solution (FNIS, A^-) are determined using equations 11 and 12, as below:

$$A^+ = (0.257, 0.257, 0.257)(0.285, 0.285, 0.285)(0.285. 0.285, 0.285)(0.222, 0.222, 0.222) (0.142, 0.142, 0.142)(0.317, 0.317, 0.317)(0.317, 0.317, 0.317)$$

$$A^- = (0.016, 0.016, 0.016)(0.022, 0.022, 0.022)(0.022, 0.022, 0.022)(0.047, 0.047, 0.047) (0.003, 0.003, 0.003)(0.067, 0.067, 0.067)(0.022, 0.022, 0.022)$$

6. Calculate the distance of each alternative by using equations 13 and 14 from FPIS and FNIS: These calculations are shown in tables 6 and 7, respectively.

TABLE 6

The distances from FPIS

Distance	C1	C2	C3	C4	C5	C6	C7	SUM
d(A1, A+)	0.118	0.204	0.204	0.121	0.096	0.099	0.099	0.941
d(A2, A+)	0.151	0.155	0.112	0.101	0.085	0.138	0.138	0.880
d(A3, A+)	0.151	0.112	0.155	0.143	0.096	0.184	0.138	0.979
d(A4, A+)	0.189	0.155	0.155	0.121	0.110	0.184	0.235	1.148
d(A5, A+)	0.151	0.155	0.204	0.121	0.110	0.184	0.235	1.159
d(A6, A+)	0.118	0.112	0.155	0.121	0.110	0.138	0.184	0.937

TABLE 7

The distances from FNIS

Distance	C1	C2	C3	C4	C5	C6	C7	SUM
d(A1, A–)	0.165	0.087	0.087	0.095	0.067	0.189	0.231	0.920
d(A2, A–)	0.121	0.137	0.190	0.115	0.088	0.150	0.190	0.992
d(A3, A–)	0.121	0.190	0.137	0.095	0.067	0.100	0.190	0.901
d(A4, A–)	0.079	0.137	0.137	0.095	0.046	0.100	0.087	0.681
d(A5, A–)	0.121	0.137	0.087	0.095	0.046	0.100	0.087	0.673
d(A6, A–)	0.165	0.190	0.137	0.095	0.046	0.150	0.137	0.921

7. Calculate the closeness coefficient of each alternative: A closeness coefficient (CC) is defined to rank all possible alternatives. The closeness coefficient represents the distances to the fuzzy positive ideal solution (A^+) and fuzzy negative ideal solution (A^-) simultaneously. The closeness coefficient of each alternative is calculated using Eq. 15.
8. Rank the alternatives according to their closeness coefficient: According to the closeness coefficient, the ranking of the alternatives can be determined in table 8. Obviously, an alternative A would be closer to FPIS and farther from FNIS as CC approaches to first. Finally, Table 8 indicated ranking of plants.

5. Results

Decision-makers face up to the uncertainty and vagueness from subjective perceptions and experiences in the decision making process. By using fuzzy TOPSIS, uncertainty and vagueness from subjective perception and the experiences of decision-maker can be effectively represented and reached to a more effective decision.

The surrounding area of Kerman sarcheshmeh copper mine area is firstly surveyed to choose the best plant type. Then a series of tests, including testing the soil, water and native plants growing in the area are performed. Sample types in this study were several crescive plant types in near the Sarcheshmeh copper mine. According to local expert's opinions obtained from questionnaires and subsequently using fuzzy TOPSIS method, results showed that the best plant types according to the regional conditions and criteria, is Amygdalus scoparia. However, Tamarix, Pistachio, Ephedra, Astragalus, Salsola, had good condition, too.

Regarding fuzzy TOPSIS analysis, it is stated that in fuzzy TOPSIS, decision makers used the linguistic variables the importance of the criteria and to evaluate the each alternative with respect to each criteria. In this study, such these linguistic variables converted into triangular fuzzy numbers and fuzzy decision matrix was formed. After normalization of fuzzy decision matrix, weighted normalized fuzzy decision matrix were formed. FPIS and FNIS were defined the most ideal in each column [(0.257,0.285,0.285,0.222,0.142,0.317,0.317) achieved in this research] and most anti ideal in each column [(0.016,0.022,0.022,0.047,0.003,0.067,0.022) achieved in this research]. Afterwards, distances of each alternative were calculated from FPIS and FNIS, shown in Tables 6 and 7. Then the closeness coefficient of each alternative was calculated separately. According to the closeness coefficient of six alternatives, the ranking order of six alternatives has been determined as A2 > A6 > A1 > A3 > A4 > A5, as shown in Table 8.

TABLE 8

Values of plant types by fuzzy TOPSIS method

1. Amygdalus Scoparia	A2 = 0.530
2. Tamarix	A6 = 0.496
3. Pistachio	A1 = 0.494
4. Ephedra	A3 = 0.479
5. Astragalus	A4 = 0.372
6. Salsola	A5 =0.367

6. Conclusions

As cited before, decision-makers face up to the uncertainty and vagueness from subjective perceptions and experiences in the decision making process. By using fuzzy TOPSIS, uncertainty and vagueness from subjective perception and the experiences of decision-maker can be effectively represented and reached to a more effective decision. In mining activities, reclamation process plays a major role in mine planning and need to be managed appropriately from environmental point of view leading to protect area from environmental impacts due to mining. With this respect, proper plant type selection is considered as an important issue in the mine reclamation process. This is carried out to meet the environmental impacts on local residents, lands and underground waters, beautifying the landscape of the region and preservation of the regional environment. The main objective of this research study is to choose the plant types for reclamation of Sarcheshmeh copper mine using Fuzzy-TOPSIS method. In this regard, primarily, surrounding area of Sarcheshmeh copper mine, one of the world's 10 biggest copper mine located near Kerman city of Iran, are surveyed to choose the best plant types for reclamation of disturbed area. A series of tests, including sampling and testing of soil, water and native plants growing in the area are then performed. Consequently, the plant type selection accomplished by using Fuzzy-TOPSIS method in accordance with expert's opinions. Results achieved from the analysis showed that the best plant type according to the regional conditions and criteria is Amygdalus scoparia. However, Pistachio, Tamarix, Ephedra, Astragalus, and Salsola had good condition, too. It is notable that other multi-criteria methods such as fuzzy PROMETHEE and ELECTRE can be used to handle plant species selection problems in the next stages.

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