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A Fuzzy-Based Methodology to Determine the Environmental Factors Affecting Pre-Mature Mine Closure: An Approach to Sustainable Mining

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Abstract: *Mine closure is regarded as the forth and the last phase of an open-pit mine planning and design. A mine will be closed when its ore reserves are totally exhausted but in some cases mines are closed due to various factors prior to the estimated reserve has been fully extracted. Among pre-mature mine closure agents, environmental factors play a major role in closure process. An appropriate investigation on environmental factors, followed by a successful mine closure plan, can result in reducing the adverse impacts of mining operations providing environmentally sustainable development. The aim of this study is to select and prioritize the environmental factors affecting pre-mature closure of an open-pit mine. With this respect, Angouran lead and zinc open-pit mine is considered as a case study. It is crucial to take into account the essential environmental criteria such as acid mine drainage, alkalinity, land or water pollution, etc.; hence, the issue is a Multi-Criteria Decision Making (MCDM) problem. This paper presents an evaluation model based on Fuzzy Analytic Hierarchy Process (Fuzzy AHP) approach, one of the most effective MCDM methods, to choose the environmental factors affecting pre-mature closure of Angouran mine. The suggested method applied to the mine and the most effective factors have been ranked and selected as pollution due to heavy metals, the presence of pyrite in the tailings and waste dumps, and sediment of chemicals with scores of 0.22, 0.21 and 0.15, respectively.*

***Keywords:** Environmental factors, Fuzzy Analytical Hierarchy Process, Multi-criteria decision making, Pre-mature mine closure, Angouran lead and zinc mine*

1. Introduction

In the present day, ‘mine closure’ process is the fourth and last period of mine planning after phases of planning, set up and production. After a mine’s deposit was excavated, that mine should be closed and the damaged areas need to be rehabilitated and reclaimed rapidly to reduce the environmental impacts of mining operations. Mine reclamation also plays a major role in the sustainable development of mining activities by establishing the environmental conditions necessary to support social (e.g. recreation), economic (e.g. forestry, agriculture) development. There exists evidence in the literary works that since the early 1990s, the mining industry has demonstrated increasing interest in social and environmental issues and it is often seeking alternatives to integrate the problems of sustainability into the core business practices [1]. Environmentally friendly development has been as part of the agendas of the mining sector [2], and various national and international initiatives have developed frameworks for sustainability. For illustration, the European Union [3] has offered priorities based on four broad issues (environmental protection, economical issues, social performance and employment, and technological and research development). The Mining Association of Canada (MAC) has proposed an initiative named “Towards Sustainable Mining (TSM)” to boost the sector’s reputation through enhancing its environmental, social and economic performance [4]. An additional example is the International Council on Mining and Metals (ICMM) has formulated 10 essential guidelines of good practice; consist of ethical management and sustainable development [5]. Nikolaou and Evangelinos [6] have performed a SWOT approach for the Greek mining industry in adopting sustainable activities. Thus, environmental issues need to be paid special attention by managers and the mine closure process requires to be conducted properly. In some cases, a mine may be closed before when its deposit fully excavated. The reasons why a mine prematurely close can be listed as environmental, economic, geological, geotechnical, regulatory, community and other socio-political pressures [7]. Premature mine closures can lead to remarkable adverse impacts on the environment, society and country’s economic such as losing jobs for personnel to build their careers or find other opportunities in other places, influencing on the local economy, safety, subsidence due to mining, acid mine drainage (AMD), land and water pollution caused by improper reclamation techniques, etc. [8]. Environmental reasons are viewed as the most important factors affecting pre-mature ~~mines~~ closure.

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Mining activities could cause long-term contamination in a region and therefore environmental impacts are considered the main causes of premature mine closure [7].

The importance of this issue is more notable when mining operations don't have adverse impacts on the environment, resulting in sustainable mining. This could be achieved by optimization of mine closure process and determination of major pollutants of the environment caused by mining. The environmental factors should be identified from the preliminary stages of mine planning and monitored and controlled over the mine's life. Any neglect to this matter might rise the environmental impacts, leading to pre-mature mine closure [7]. A number of studies have been accomplished with respect to mine closure. Laurence [8] developed a risk assessment procedure that examines the major risks related to mine closure. These attempts yield a classification approach for quantifying mine closure dangers to be utilized by mine operators and regulators seeking to minimize the effects of both premature and planned mine closure. Laurence grouped the reasons why mines close as follows: closure due to environmental, social, economic, geotechnical, geological reasons, mechanical or equipment failure, regulatory issues, country's policy, NGOs opposition and other reasons. Sango et al. [9] have investigated the social and biophysical influences that emanated from the unexpected closure of Mhangura copper mine caused by persistent viability problems. It was observed that no environmental impact assessment was carried out before the inception of the mine. Most importantly, it was the absence of a mine closure plan for rehabilitation and sustained community livelihood. The physical environment was in many parts left in a state of dereliction, pausing a host of ecological, health and safety risks to the community, livestock, other biota and property.

There is ample evidence that environmental reasons contribute to mine closure. As an example, the Bunker Hill mine complex is situated in northwest Idaho in the Coeur d'Alene River Valley, and has a legacy of almost a hundred years of mining related pollution since 1889. Operations halted in 1982, and the EPA declared much of the area a Superfund region in 1983. The complex was a source of lead, zinc, silver, and gold, cadmium, as well as arsenic and other materials and minerals. Much of the mining pollution was induced by the dump of mining wastes containing such contaminants as cadmium, arsenic, and lead into the floodplain of the Coeur d'Alene River, AMD, and a leaking tailings disposal. The metals polluted surface water, groundwater, air, and soils, resulting in environmental and health problems. Lead, was particularly mentioned because of its health effects on children in the area [10]. In most Latin American countries, the environmental protective measures had remained a low priority due to political and economic crises during the 1980s. It is truly after the 1990s that the context and the impetus for the emergence of environmental control have been set [11].

Driussi and Jansz [12] suggest that some particular management approaches such as environmental management techniques, pollution prevention technologies and environmental awareness may help companies to enhance their accountability in association with environmental issues. Other experts have investigated the relations between environmental degradation and conflict, and have analyzed the links between social and environmental variables (poverty, resource scarcity, democracy, resource abundance, and population growth). They found that those countries undergoing important political and economic transitions, and the ones with limited political and economic resources, are more susceptible to internal violent conflicts [13].

One of the most effective Multi Criteria Decision-Making (MCDM) approaches is Fuzzy Analytical Hierarchy Process (FAHP). An FAHP is able to reflect human thought in that it uses approximate information and uncertainty to generate proper decisions. In the FAHP, calculations are performed using fuzzy numbers. There are many fuzzy AHP applications in the literature proposed by various authors. Van Laarhoven and Pedrcyz [14] presented the first studies that applied fuzzy logic theory to AHP. Buckley [15] utilized trapezoidal fuzzy numbers to explain the decision maker's assessment on alternatives regrding each criterion, while Van Laarhoven and Pedrcyz [14] have used triangular fuzzy numbers. Chang [16] released a novel approach for dealing with FAHP, with the use of triangular fuzzy numbers for pair-wise evaluation scale of FAHP, and the application of the extent analysis principle for the synthetic extent values of the pair-wise comparisons. Deng [17] introduced a fuzzy procedure for tackling qualitative MCDM problems in a simple way. Zhu et al. [18] proved the basic theory of the triangular fuzzy number and improved the formulation of comparing the triangular fuzzy number's size. On this basis, they introduced a practical example on petroleum prospecting. Leung and Cao [19] proposed a fuzzy consistency definition with consideration of a tolerance deviation. Essentially, the fuzzy ratios of relative importance, allowing certain tolerance deviation, were formulated as constraints on the membership values of the local priorities. Chou and Liang [20] proposed a fuzzy multi-criteria decision making model by combining fuzzy set theory, AHP and concept of entropy, for shipping company performance evaluation. Bozdag et al. [21] proposed four different fuzzy multi-attribute group decision making methods to select the best computer integrated manufacturing system. One of these methods is FAHP and the others are Yager's weighted goals method, Blin's approach and fuzzy synthetic evaluation. Chang et al. [22] developed a methodology for performance evaluation of airports. They used the gray statistics method in selecting the criteria, and FAHP method in determining the weights of criteria. And finally they adopted fuzzy synthetic and TOPSIS approach for the ranking of airport performance. Kahraman et al. [23] used FAHP to select the best supplier firm providing the most satisfaction for the criteria determined. Hsieh et al. [24] introduced a fuzzy MCDM approach to choose the design alternatives in public office structures. The Fuzzy AHP analysis is widely utilized to determine the weightings evaluated by decision makers. Mikhailov and Tsvetinov [25] used a new fuzzy improvement of the AHP for evaluation of services. The proposed fuzzy prioritization method uses fuzzy pair-wise comparison judgments rather than exact numerical values of the comparison ratios and transforms initial fuzzy prioritization problem into non-linear program. Enea and Piazza [26] focused on the constraints that have to be considered within FAHP. They used constrained FAHP in project selection. Kahraman et al. [27] used the FAHP for comparing catering companies in Turkey. The experts and customers produced the means of the triangular fuzzy numbers for each comparison which successfully used in the pair-wise comparison matrices. Tang and Beynon [28] used FAHP method for the application and development of a capital investment study. They tried to select the type of fleet car to be adopted by a car rental company. Tolga et al. [29] used fuzzy replacement analysis and AHP in the selection of operating system. The economic part of the decision process had been developed by fuzzy replacement analysis. Non-economic factors and financial figures had been combined by using a FAHP approach. Basligil [30] proposed an analytical strategy for selecting the suitable software leading to the most customer satisfaction. Tang et al. [28] proposed a multi-objective model for Taiwan notebook computer distribution problem. Their model involves a mixed integer programming and fuzzy analytic hierarchy process approach. Gu and Zhu [31] constructed fuzzy symmetry matrix as attribute evaluation space based on fuzzy decision matrix and improved the FAHP method using the approximate fuzzy eigenvector of such fuzzy symmetry matrix. Tuysuz and Kahraman [32] provided an analytical tool to evaluate the project risks under incomplete and vague information. They used FAHP to evaluate the riskiness of an information technology project of a Turkish company. Ayag and Ozdemir [33] proposed an intelligent approach based on FAHP for evaluating machine tool alternatives. They firstly used FAHP to weight the alternatives under multiple attributes and then carried out benefit/cost ratio analysis by using both the FAHP score and procurement cost of each alternative. Ertugrul and Karakasoglu [34] proposed to use FAHP to select the best supplier for a textile firm in Turkey. Haq and Kannan [35] proposed a structured model for evaluating vendor selection using AHP and FAHP. Chan and Kumar [36] proposed a model for providing a framework for an organization to select the global supplier by considering risk factors. They applied fuzzy AHP for choosing a global supplier. Ertugrul and Karakasoglu [37] utilized both FAHP and TOPSIS approaches for evaluating Turkish cement factories performance.

ZareNaghadehi et al. [38] have utilized FAHP approach to select the best mining method for a Bauxite Mine in Iran. Bangian et al. [39] have selected optimum alternative for a post mining land use problem using fuzzy analytical hierarchy process. Alavi [40] used Fuzzy AHP method for plant species selection for reclamation plan of Songun copper mine. Shi et al. [41] improved classification of surrounding rock in tunneling according to fuzzy analytic hierarchy process as well as tunnel seismic prediction. Ebrahimabadi [42] used a fuzzy methodology to select the proper roadheader in Tabas coal mine project of Iran.

The objective of this research work is to choose the environmental factors affecting pre-mature mine closure. Since the various environmental factors are involved in the mine closure, the selection process of these factors is a Fuzzy MCDM Process such as FAHP. In section 2 of the paper, a brief review is presented on why mines close. In section 3, the concepts of the fuzzy sets and fuzzy numbers as well as FAHP method arebriefly described. This section includes the literature review and also the methodology of FAHP method. In section 4, after introducing the study area and the hierarchy structure of problem, the FAHP method is applied for determining the weights of the criteria. Then, subsequent calculations and analyses are conducted and finally environmental factors affecting the premature mine closure are prioritized and selected. Eventually, in sections5 and 6, a discussion on used method and conclusions of the paper are presented.

2. Why do mines close?

In a perfect world, mines close when their reserves are exhausted. In many respects, this is the easiest scenario to manage. In these cases, the various stakeholders are conditioned to the planned closure date. Employees, for example, can plan to find alternative employment either with the company or elsewhere. The community in which the mine operates is furnished with the opportunity to work with the mine to ensure sustainable benefits from its activities, although it should be remembered that communities, and sometimes employees, are often in denial and unprepared for the consequences of closure. This is particularly true in towns. Where mining has taken place for many decades. Governments have no doubt maximized their benefits in the form of taxes and royalties and should be working with the mine to ensure that environmental outcomes are optimum and in line with the objectives stipulated within the closure or environmental management plan. Mines close for a variety of reasons that they include [43, 44].

2.1 Closure due to environmental reasons

Adopting leading environmental management practices on mine sites makes excellent business sense. Unless steps are taken in the planning and operational stages to protect environmental values, long-term liabilities such as acid mine drainage, may result. Thanks in part to the increasing awareness of environmental issues, there is considerable literature relating to the environment and sustainable development. This dimension includes the concepts of ecosystem integrity and natural resource productivity. The new context, however, is the interaction between mining, global warming and other significant emerging issues [45]. Mining activities can cause contamination of water, air, soil, land and flora and fauna species in the around surrounding area of mining site. Mining activities can also cause the pollution of surface water, groundwater and the water used for drinking and agricultural purposes by precipitation, acid generation, salinity, presence of heavy metals and contaminants materials. Gases resulting from the explosion and obtained greenhouse gases, as well as dust due to the existing very fine particles in the dam of tailing and stockpile lead to the soil and air pollution around the mine site. Existence of infrastructure, storages, repair shops, and dumps result in reducing the beauty of landscapes especially near the big cities [7]. Additional noises can have harmful effects on humans and wildlife, bringing disturbance and disruption of comfort [46]. Moreover, environmental pollution will cause terrible damages on species of flora and fauna by changing the existing ecosystems in the region [7]. The potential for environmental disasters such as those that occurred at Baia Mare, Los Frailos, Omai, OK Tedi and many more are ever present however. These events are subjected to criticism long after the event and a recent example is Whitmore's [47] analysis of the Summitville mine acid mine drainage catastrophe of 1992. Numerous catastrophic releases of toxic materials have occurred in the Balkans, one of the most high-profile being the failure of the Baia Mare tailings dam in Romania. In January 2000 the facility overflowed, releasing 100,000 cubic meters of cyanide-contaminated effluent into the Tisza River. By the time the overflow was detected, the heavily contaminated waste water had reached the Danube and was on its way to Hungary and beyond. Large quantities of cyanide entered the drinking water of numerous towns in seven countries and water supplies serving thousands of people and agriculture. Traces of cyanide, albeit at a very low level, could still be detected in the river water when it reached the Black Sea two weeks later. One well-known example of a mining-related environmental accident and long-term deterioration is Rio Tinto, a river in southern Spain. Research suggests that ancient (and modern) mining activities around the Rio Tinto have caused highly acidic conditions in the entire river system creating hostile living conditions and high concentrations of heavy metals which have persisted for millennia. During the 20th century mining accidents caused death and injuries all over the world. In 1966 the collapse of a colliery spoil heap in Aberfan, Wales, killed 144 people, including 116 children [48]. Therefore, mining activities can be the sources of long-term pollution in a region and so, environmental issues are considered the main reasons for mine closure [7]. With this respect, one of the major reasons to establish an environmental management approach is society intention to have a cleaner and sustainable environment [13]. In this context, mine closure plan and identification, monitoring and controlling the mining impacts on the environment are necessary throughout the whole mine\s life to have an environment without environmental pollution resulting from mining activities providing fully extraction of mine's deposit.

2.2 Closure due to economic reasons

One of the best-known examples of ‘‘mass’’ mine closures occurred in October 1985, when the price of tin dropped dramatically after the collapse of the Internal Tin Agreement at the London Metal Exchange. The price dropped more than 50%, from US$5.40/pound to $2.50; numerous mines could no longer remain in operation. This naturally had an impact on large companies, but particularly affected the small-scale tin miners operating, for instance, in Tingha and Emmaville, Australia. The outcomes were significant environmentally (numerous unrehabilitated open cuts and waste dumps) and detrimental economically for mine workers, mine owners and communities. The effects in other countries were even more dramatic, such as in Bolivia, where a reported 50,000 miners lost their livelihoods [43, 44].

2.3 Closure due to geological reasons

Ore reserves are estimates based on the best available data provided by geological, geophysical, geochemical and drilling techniques, and by other relevant means. An over-estimation of the grade and tonnage of a deposit is a common reason for a mine to close prematurely. The Mount Todd Mine in the Northern Territory is one such example. Here, head grades were estimated at over 1 g/tonne but averaged a little over 0.8 g for the life of the mine. The mine closed after one year, although the expected mine life was more than nine years Similarly, Cumnock Coal in the Hunter Valley of NSW closed in 2003 due to ‘‘adverse geological conditions’’. The Chief Executive Officer further indicated, whilst it is very disappointing to see the underground mine close and employees lose their jobs, I am comforted by the fact that due to Xstrata Coal's financial support to date we have been able to extend the mine's life and ensure the continuity of operations and employment. Furthermore, as a result of this financial support, Cumnock Coal is able to meet all employee entitlements in full [43, 44].

2.4 Closure due to geotechnical reasons

Mining takes place in a non-homogeneous rock mass, which varies from site to site. Imperfections in the rock in the form of joints, cleavages, cleats, and otherplanar weaknesses, combined with faults, shear zones and hydrological issues, can lead to failure of the rock mass. Falls in underground workings have caused the premature closure of many mines, including the Tom's Gully Mine in the Northern Territory, wherethe decline intersected a fault and the developmentfailed to overcome the resultant poor ground conditions. The most spectacular closure in Australia in recent years due to geotechnical reasons was the 1998 hanging wall or stopefailure at the Browns Creek Mine in central NSW, and the subsequent inrush and filling of the mine with water overnight; the mine has never reopened. Inrush also caused the deaths of four coal miners and the closure of the Gretley Coal Mine in NSW in 1996. Although there were minimal environmental issues, the social and community fallout has been considerable, with prosecutions of the company and individual managers continuing (December 2003). Pit slope failures in open pit mines can cause permanent mine closures and most recently caused the deaths of eight workers at the massive Grasberg open cut mine in Indonesia, operated by PT Freeport. The mine closed temporarily after this incident [43, 44].

2.5 Closure due to equipment or mechanical failure

Mine closures due to equipment failure have been a part of mining history. One of the most notorious cases was the Hartley mine in the United Kingdom, which closed in 1862 when its Cornish Beam pump collapsed into the shaft used to ventilate the mine. As a result, 199 miners perished due to lack of air [43, 44].

2.6 Closure due to regulatory pressure

Government regulators generally have the power to close mines due to environmental or safety breaches.A recent, highly publicized example is the Baia Mare mine in Romania. This mine also had the pressure of the Australian Stock exchange suspending trading in its shares operations at the Mt Kasi Mine were stopped for over six weeks by the Government of Fiji for failure to contain tailings. The Northparkes mine temporarily closed in 1999, following an incident resulting in the deaths of four personnel [43, 44].

2.7 Closure due to government policy

Minerals and mining on the coasts of New South Wales and Queensland is almost extinct because of government policies, which, in response to community pressure, give land use preference to National Parks over mineral resources. The operations of Dillingham were prematurely closed by the Federal Government in 1976 at Fraser Island in Queensland after the Fraser Island environmental inquiry found that mining constituted a significant threat to the island's environment. The re-opening of the Woodsreef asbestos mine in northern NSW was stymied due to the controversy surrounding the mining of asbestos. The author was involved in the regulation of both mineral sand and asbestos mining in the 1980s [43, 44].

2.8 Closure due to community opposition

The Timbarra gold mine in NSW closed in 2001 due in part to the continued opposition to its operation by an alliance of opposition groups. The low grades sent to the mill and persistent wet conditionsduring its construction and early operations also contributed to its premature closure. The Jabiluka Uranium Mine operated as a development operation only (i.e. noproduction of uranium) in the face of highly organized opposition from environmental and community groups for almost two years before operations halted The owner, Rio Tinto, has indicated it will not recommence mining at Jabiluka until the traditional owners are supportive of mining [43, 44].

2.9 Closure due to other reasons

Occasionally, mines close before their reserves are exhausted due to reasons other than those indicated above. For example, the coal mining operations at Catherine Hill Bay in NSWclosed after the company was sold to a buyer who wanted to develop the area for its prime real estate appeal [43, 44].

3. Fuzzy sets and fuzzy numbers

To handle vagueness of human guess, Zadeh [49] first suggested the fuzzy set theory, which was focused to the rationality of uncertainty caused by vagueness or imprecision. Indicating vague data could be considered a major capability of fuzzy set theory. In this theory, mathematical programming can be involved through the analysis. A fuzzy set is a category of objects with consistent grades of membership. This set is determined via a characteristic (membership) function, which designates to each object a grade of membership varying between zero and one.

Because of extensive diversity of decision making cases, the achieved results can be misleading if the human's decision making fuzziness is not considered [50]. Fuzzy approach, provides a more widely framework than conventional methods, is being applied to reflect the real world [51]. Fuzzy sets and fuzzy logic are powerful mathematical tools for modeling the uncertainty issues in decision making problems when enough data is not provided. The role of these tools is remarkable when the problem cannot be easily explained through conventional mathematical approaches, particularly when the objective is to discover a good mimic solution [52]. Fuzzy set theory is an improved means to model imprecision stemming from mental tendency which are neither arbitrary not stochastic. A sensible strategy toward decision making should include individual subjectivity, rather than using merely objective probability measures. Such view towards imprecision of human behavior causes fuzzy oriented analysis for a new decision making problem [53].

If the symbol '~' is placed above a number, that number is identified as a fuzzy number; a triangular fuzzy number (TFN), $\tilde{M}$ is demonstrated in Figure 1. A TFN is indicated in a plain manner as *(l/m,m/u)* or (l, m, u). The parameters l, m and u, denote the smallest feasible value, the most appealing value, and the greatest feasible value, correspondingly, that identify a fuzzy event.

A TFN has linear illustration on its left and right side in a way that the membership function can be explained as:

$$\mu_{\tilde{A}}(x) = \begin{cases} 0, & x \le l \\ (x-l)/(m-l), & l \le x \le m \\ (u-x)/(u-m), & m \le x \le u \\ 0, & otherwise \end{cases} \qquad (1)$$

A fuzzy number can always be given by its corresponding left and right representation of each degree of membership:

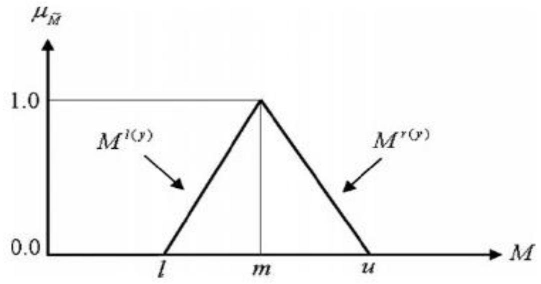

***Figure 1**: A triangular fuzzy number,$\tilde{M}$ [16]*

$$\tilde{M} = \left(M^{l(y)}, M^{r(y)}\right) = \left(l + (m-l)y, u + (m-u)y\right)$$
$$y \in [0, 1] \qquad (2)$$

Where l(y) and r(y), respectively, indicate the left and the right side representation of a fuzzy number. There are a number of prioritizing methods for fuzzy numbers in the literature. These methods can provide various ranking results. Most methods are also boring in graphic assessment requiring complex mathematical computation. The algebraic functions for fuzzy numbers can be found in Kahraman [54] and Kahraman et al. [55].

3.1 Fuzzy analytic hierarchy process (FAHP)

The analytic hierarchy process (AHP) is an approach that is appropriate for tackling complex systems associated with making a choice among several options and which provides a comparison of the considered options, proposed firstly by Saaty [56]. The AHP is based on the subdivision of the problem in a hierarchical manner. Actually, this method helps organize the rational analysis of the problem via dividing it into its single parts; the analysis then supplies an aid to the decision makers who, making several pair-wise comparisons, can appreciate the influence of the considered elements in the hierarchical structure; the AHP can also give a preference list of the considered alternative solutions [56, 57, 58, 59]. The AHP is a tool that can be used for analyzing different kinds of social, political, economic and technological problems, and it uses both qualitative and quantitative variables. The fundamental principle of the analysis is the possibility of connecting information, based on knowledge, to make decisions or previsions; the knowledge can be taken from experience or derived from the application of other tools. Among the different contexts in which the AHP can be applied, mention can be made of the creation of a list of priorities, the choice of the best policy, the optimal allocation of resources, the prevision of results and temporal dependencies, the assessment of risks and planning [58]. Though the AHP uses the expert's opinion, the traditional AHP still cannot properly reveal the human thinking manner [60]. The AHP method is controversial in that it uses an accurate value to indicate the decision maker's judgment in dual comparisons [61]. Also, it is often criticized because it uses unbalanced scale of opinions and it is not capable to adequately cope with the inherent uncertainty and imprecision in the pair-wise comparisons [17]. To dominate whole these limitations, FAHP was introduced for dealing with the hierarchical problems. Decision makers usually find that it is somewhat more confident to give interval judgments than fixed value judgments. This is due to his/her inability to explicit preference with respect to the fuzzy nature of the comparison process [60]. This paper proposes the use of FAHP for determining the weights of the main criteria.

3.2 Methodology of FAHP

In current study, the extent FAHP, which was originally developed by Chang [16], is utilized. Suppose $X = \{x_1,x_2,x_3, ...,x_n\}$ is an object set, and $G = \{g_1,g_2,g_3, ...,g_n\}$is a goal set. In accordance with Chang's extent analysis, every object is taken and sequentely, extent analysis for each goal is carried out. Thus, m extent analysis values for each object can be represented as follows [16]:

$$M_{gi}^1, M_{gi}^2, \dots, M_{gi}^m, \qquad i=1,2,3,\dots,n \qquad (3)$$

Where the $M_{gi}^j (j=1, 2, 3, \dots, m)$ all are TFNs. The Steps of Chang's extent analysis are performed as below:

Step 1: Defining the value of fuzzy synthetic context with respect to ith object, as Eq. (4):

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} \qquad (4)$$

To obtain $\sum_{j=1}^{m} M_{gi}^{j}$ (Fuzzy Summation of Row), the fuzzy addition operation of m extent analysis values for a particular matrix should be provided, such Eq. (5):

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \qquad (5)$$

And to achieve, $\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1}$ conduct the fuzzy addition operation of M_{gi}^{j} *(j=1, 2…, m)* values such Eq.(6): (Summation of Column)

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right) \qquad (6)$$

And then caculate the inverse of the vector in Eq. (7) such that:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(1/\sum_{i=1}^{n} u_i, 1/\sum_{i=1}^{n} m_i, 1/\sum_{i=1}^{n} l_i\right) \quad (7)$$

Step 2:

Since $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$ are two triangular fuzzy numbers, the degree of possibility of $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ can be defined using Eq. (8).

$$V\ (M2 \geq M1) = \sup_{y \geq x}\left[\min\left(\mu_{M1}(x), \mu_{M2}(y)\right)\right] \quad (8)$$

And can be equivalently indicated as Eq. (9-10):

$$V\ (M_2 \geq M_1) = hgt\ (M_1 \cap M_2) = \mu_{M2}(d) \qquad (9)$$

$$(M_2 \geq M_1) = \begin{cases} 1 & \text{if } m_2 \geq m_1 \\ 0 & \text{if } l_1 \geq u_2 \\ l_1 - \dfrac{u_2}{(m_2 - u_2)} - (m_1 - l_1) & \text{otherwise} \end{cases}$$

Where d is the coordinate of highest intersection point D between μ_{M1} and μ_{M2} (Figure 2). To compare M_1 and M_2, we need to have both values of $V\ (M_1 \geq M_2)$ and $V\ (M_2 \geq M_1)$

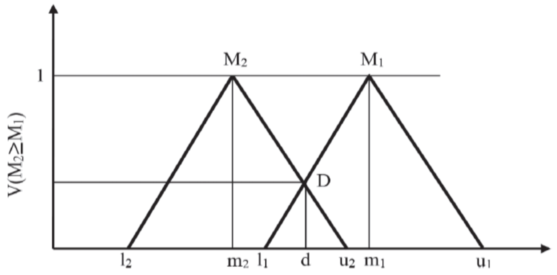

***Figure 2**: The intersection between M1 and M2 [16]*

Step 3: The degree of possibility for a convex fuzzy number to be greater than k convex fuzzy $M_i (i = 1,2, \dots, k)$ numbers can be explained via Eq. (11).

$$V\ (M \geq M_1, M_2, \dots, M_k) = V\ [(M \geq M_1)\ and\ (M \geq M_2)\ and \dots and\ (M \geq M_k)] = Min\ (M \geq M_i) \quad i = 1, 2, 3, \dots, k \qquad (11)$$

Suppose the Eq. (12) is as follow:

$$d'(A_i) = \min V\ (S_i \geq S_k) \qquad (12)$$

for $k = 1, 2, \dots, n; k \neq i$

Then the weight vector is calculated by using Eq. (13)

$$W' = (d'(A_1), d'(A_2), \dots, d'(A_n))^T \quad (13)$$

Where $A_i\ (i = 1, 2, \dots, n)$ are n elements.

Step 4: The normalized weight vectors are achieved via normalization process, by using Eq. (14).

$$W = (d(A_1), d(A_2), \dots, d(A_n))^T \qquad (14)$$

Where W is a non-fuzzy number.

Step 5: Determine the alternatives of final weight, by using Eq. (15).

$$A_1 = (A_1\ to\ C_1 \times C_1\ to\ GOAL) + (A_1\ to\ C_2 \times C_2\ to\ GOAL) + (A_1\ to\ C_3 \times C_3\ to\ GOAL) + \dots + (A_1\ to\ C_n \times C_n\ to\ GOAL) \qquad (15)$$

Where n is the number of criteria.

4. Selecting and prioritizing environmental factors affecting premature closure of Angouran lead and zinc mine

4.1 The introduction of study area

Angouran lead and zinc mine is the Iran's largest lead and zinc mine, as well as in the Middle East. Angouran lead and zinc processing plant is the biggest producer of lead and zinc in Iran. The mine is located near Dandi and Mahneshan cities and situated 135 km far from western Zanjan city in Zanjan province (Figure 3). Its latitude and longitude are 36° 37' and 47° 24°, respectively. All mining operations in this region are under supervision of Iran Minerals Production and Supply Company (IMPASCO). The mine site is located in a mountainous terrain with cold climate condition. Average temperature in winter is -15 centigrade [62]. The mine's ore reserve (mainly Cerusite and Smithsonite) is estimated nearly 12 million tons. The mine is an open-pit mine with 14 benches. The overall pit slope is 45 degree with bench slope of 70 degree. Future open-pit mining has been planned for next 12 years.

The lead and zinc processing plant, in the city of Dandi with a capacity of about 140 tons per hour, is located 100 km far fromsouthwest of Zanjan. Excavated ore from the mine (situated at a distance of 20km from the plant) is used as the feed for this plant. The plant has been designed to handle two types of feeds i.e. low- and high grade zinc ores. The plant has been equipped and installed from 1973-1979. The high grade ore contains 10% lead and 35% zinc while the low grade ore averages 7% lead and 22% zinc. The products of the processing plant consist of zinc concentrate with 38% zinc, lead concentrate grading 60% lead, and calcined zinc concentrate with 52% zinc [62].

***Figure 3:** The location of Angouran region*

4.2 Selection of environmental factors affecting pre-mature closure of Angouran open-pit mine

There are various environmental factors playing a role in pre-mature mine closure, listed in Table 1. The first step to choose the environmental agents, based on FAHP, is to determine the criteria, sub-criteria (if any) and alternatives. With respect to Table 1, the main factors (criteria) regarding mine closure can be summarized and categorized into main broad issues such as toxicity, acidity, water pollution, (groundwater, surface, downstream), air pollution, noise pollution, close to population and a threat to agricultural and ecosystem areas [7, 9, 10, 44, 46, 48, 63, 64, 65, 66].

According to results obtained from the open-pit mining experts' opinion, the major environmental factors (alternatives) affecting premature mine closure prioritized as: 1. The presence of pyrite in tailings and waste damps, 2. The presence of heavy metals pollutants, 3. Emission or sediment of chemical material, 4. The presence of hazardous material such as cyanide or radioactive materials, 5. The presence of sewage, fuels and oils, 6. Problems stems from blasting (ground vibration, dust, air noise, fly rock), 7. The destruction of the landscape area, 8. Landslides and ground settlement,

***Table 1:** Environmental issues affecting premature mine closure [7, 8, 10, 46, 63, 64, 65, 66, 67, 68]*

No	Environmental issues affecting premature mine closure
1	Sedimentation
2	Water pollution (Chemicals, sewage, heavy metals)
3	sewage of Mining facilities
4	Water pollution by heavy metals
5	Acid Mine Drainage (AMD)
6	Salinity
7	Water temperature increase
8	Subsidence (due to change in water table condition)
9	Hazardous material (such as cyanide or radioactive materials)
10	Destruction of agriculture, habitat and grazing in the area
11	Soil contamination
12	Contamination of aquatic ecosystems
13	Greenhouse gas emissionsOther emissions (e.g. SO2)
14	Dust (Blasting, mill, tailings, stockpiles)
15	Dust and noise production from factories
16	Additional Voices, Sound effects on humans and wildlife, Harassment and The loss of comfort
17	Close to population or main roads
18	Changr in surface water flows
19	Infrastructure: Buildings, equipment, camps, Roads, Stockpiles, dumps, dams, sumps Borrow pits
20	Damage to the monuments, cultural and historical constraction،
21	Soils contamination
22	Inaccessibility to suitability Topsoil
23	Topsoil unavailability and erosion potential
24	Regional ecosystem destruction
25	Impossibility of restore all the animals (aquatic, aerobic, or both)
26	Risk of extinction the plant and animal species
27	Voids: Open or Backfill (using waste rock)
28	created Hazards Caused by the sudden failure of dams For downstream industries
29	landslide potential
30	Liquefaction, flood and runoff in tailings
31	Tailings subsidence
32	Reshaping of waste Dump
33	Inappropriate covers of waste dumps
34	AMD of waste dump

9. Damage to protected areas and monuments, 10. Change in the conditions of the underground water table [7, 9, 10, 44, 46, 48, 63, 64, 65, 66, 67, 68]. Based on the above criteria and alternatives, the hierarchical structure of the problem is shown in Figur 4.

Fuzzy AHP method has a significant potential as a tool for decision makers so that they can choose the main alternatives of premature mine closure with using this method with systematic manner in the mine sites. This method is based on teamwork to ensure that all issues affecting mine closure are considered. Questionnaires were prepared, including the pair-wise comparison of criteria and alternatives than the criteria for prioritizing environmental factors affecting premature closure of Anguran lead and zinc mine, and were given to theexperts atAngouranlead and zinc mine and as well as experts in environmental issues, in general, for scoring by triangular fuzzy numbers according to their importance relative to each other. The importance of each criteria and alternatives using the fuzzy numbers are listed in Table 2.

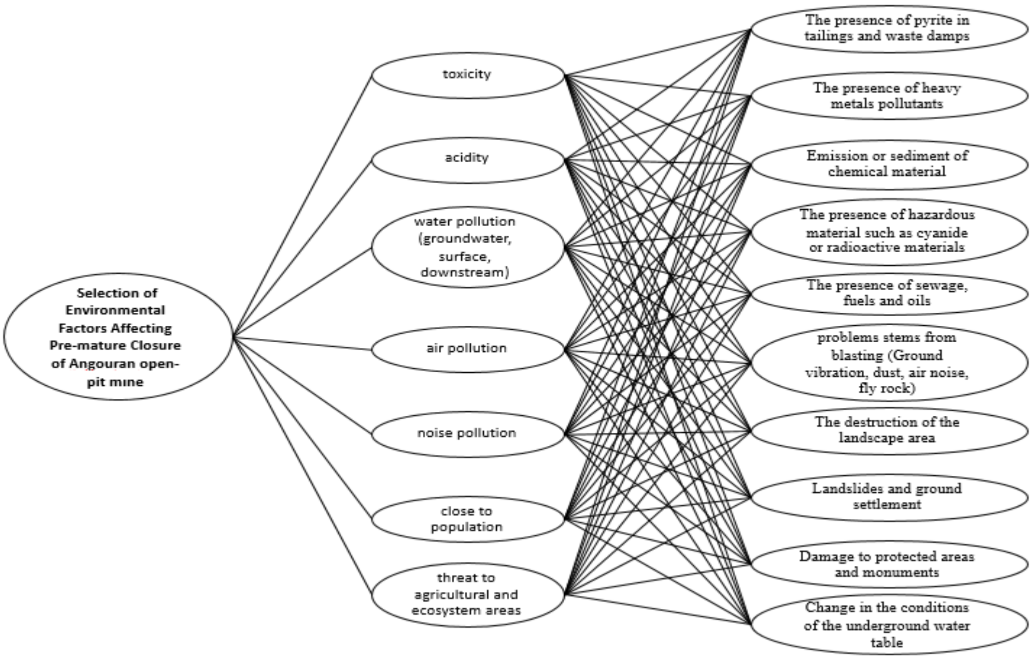

***Figure 4**: Hierarchical structure of the problem*

***Table 2:** Triangular fuzzy Numbers and their description [69]*

Triangular Fuzzy Numbers	Description	Fuzzy Number
(7,9,9)	Absolute importance	9
(5,7,9)	Very strong importance	7
(3,5,7)	Strong importance	5
(1,3,5)	Weak importance	3
(1,1,3)	Same importance	1

In the first stage, hence, a comprehensive matrix is obtained for each of pair-wise comparison matrixesof criteria and alternatives. It should be stated that we used geometric mean values of scores provided by experts, according to Eq.(16).

$$l_{ij} = \left(\prod_{k=1}^{k} l_{ijk}\right)^{\frac{1}{k}}, m_{ij} = \left(\prod_{k=1}^{k} m_{ijk}\right)^{\frac{1}{k}}, u_{ij} = \left(\prod_{k=1}^{k} u_{ijk}\right)^{\frac{1}{k}} \qquad (16)$$

For more clarification and as an example, table 3 and table 4 demonstrate the pair-wise comparison of criteria(in general)and alternatives with respect to noise pollution criterion, respectively.

***Table 3:** Pair-wise comparison matrix of criteria*

	Toxicity	Acidity	Water pollution, (groundwater, surface, downstream)	Air pollution	Noise pollution	Close to population	Threat to agricultural and ecosystem areas
Toxicity	1 1 1	2.1 4.22 6.26	1.442 3 5.14	1.57 3.13 5.36	4.52 6.9 8.16	2.87 4.22 6.34	1.9 3.41 5.66
Acidity	0.16 0.24 0.5	1 1 1	1.2 2.72 4.86	1.44 3 5.14	3 4.28 6.6	2.5 3.82 6.1	1.44 3 5.14
Water pollution, (groundwater, surface, downstream)	0.22 0.33 0.7	0.21 0.37 0.83	1 1 1	1.2 3.27 5.29	3.46 5.51 7.3	2.72 4.86 6.9	1 3 5

Air pollution	0.19 0.32 0.64)	0.2 0.33 0.7	0.19 0.31 0.83	1 1 1	2.1 4.22 6.26	2.1 3.51 5.75	1 2.5 4.6
Noise pollution	0.12 0.14 0.22	0.15 0.23 0.33	0.17 0.18 0.3	0.16 0.24 0.5	1 1 1	1 2.1 4.22	0.248 0.585, 0.691
Close to population	0.16 0.27 0.35	0.16 0.26 0.4	0.14 0.21 0.37	0.17 0.3 0.5	0.24 0.5 1	1 1 1	1 3 5
Threat to agricultural and ecosystem areas	0.18 0.3 0.53	0.19 0.33 0.7	0.2 0.33 1	0.22 0.4 1	1.447 1.709 4.032	0.2 0.33 1	1 1 1

***Table 4**: Pair-wise comparison matrix of alternatives with respect to noise pollution criterion*

Sound pollution	The presence of pyrite in tailings and waste damps	The presence of heavy metals pollutants	Emission or sediment of chemical material	The presence of hazardous material such as cyanide or radioactive materials	The presence of sewage, fuels and oils	problems stems from blasting (Ground vibration, dust, air noise, fly rock) dust	The destruction of the landscape area	landfall and ground settlement	Damage to protected areas and monuments	Change in the underground water table
The presence of pyrite in tailings and waste damps	1 1 1	1 1 3	1 1 3	1 1 3	1 1 3	0.12 0.14 0.21	1 1 3	1 1 3	1 1 3	1 1 3
The presence of heavy metals pollutants	0.33 1 1	1 1 1	1 1 3)	1 1 3	1 1 3	0.12 0.14 0.21	1 1 3	1 1 3	1 1 3	1,1,3)
Emission or sediment of chemical material	0.33 1 1	0.33 1 1	1 1 1	1 1 3	1 1 3	0.12 0.14 0.21	1 1 3	1 1 3	1 1 3	1 1 3
The presence of hazardous material such as cyanide or radioactive materials	0.33 1 1	0.33 1 1	0.33 1 1	1 1 1	1 1 3	0.12 0.14 0.21	1 1 3	1 1 3	1 1 3	1 1 3
The presence of sewage, fuels and oils	0.33 1 1	0.33 1 1	0.33 1 1	0.33 1 1	1 1 1	0.12 0.14 0.21	1 1 3	1 1 3	1 1 3	1 1 3
problems stems from blasting (Ground vibration, dust, air noise, fly rock) dust	4.76 7.14 8.33	4.76 7.14 8.33	4.76 7.14 8.33	4.76 7.14 8.33	4.76 7.14 8.33	1 1 1	2.82 3.87 6.03	2.43 3.71 5.9	2.43 3.71 5.9	7 9 9
The destruction of the landscape area	0.33 1 1	0.33 1 1	0.33 1 1	0.33 1 1	0.33 1 1	0.17 0.26 0.35	1 1 1	1 1 3	1 1 3	1 1 3
Landslides and ground settlement	0.33 1 1	0.33 1 1	0.33 1 1	0.33 1 1	0.33 1 1	0.17 0.26 0.41	0.33 1 1	1 1 1	1 1 3	1 1 3
Damage to protected areas and monuments	0.33 1 1	0.33 1 1	0.33 1 1	0.33 1 1	0.33 1 1	0.17 0.27 0.41	0.33 1 1	0.33 1 1	1 1 1	1 1 3
Change in the underground water table	0.33 1 1	0.33 1 1	0.33 1 1	0.33 1 1	0.33 1 1	0.11 0.11 0.14	0.33 1 1	0.33 1 1	0.33 1 1	1 1 1

When the comprehensive matrix of pair-wise comparison completed, normalized weight vectors are obtained using fuzzy AHP method.

For example, calculation of the pair-wise comparison matrix of criteria and alternatives with respect to noise pollution criteria using FAHP method provided as below:

The calculation of the pair compared criteria: According to the FAHP method, firstly synthesis values must be calculated. From Table 3, synthesis values respect to main goal are calculated like in Eq. (4-7):

$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1}$ = (0.0072, 0.0113, 0.0193)

$S_i = \sum_{j=1}^{m} M_{gi}^{j} \times \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1}$

S_{c1} = (15.402, 25.88, 37.92) × (0.0072, 0.0113, 0.0193) = (0.111, 0.292, 0.732)

S_{c2} = (10.74, 18.06, 29.34) × (0.0072, 0.0113, 0.0193) = (0.077, 0.204, 0.566)

S_{c3} = (9.81, 18.34, 27.02) × (0.0072, 0.0113, 0.0193) = (0.071, 0.207, 0.521)

S_{c4} = (6.78, 12.19, 19.78) × (0.0072, 0.0113, 0.0193) = (0.049, 0.138, 0.382)

S_{c5} = (2.848, 4.475, 7.261) × (0.0072, 0.0113, 0.0193) = (0.021, 0.051, 0.14)

S_{c6} = (2.87, 5.54, 8.62) × (0.0072, 0.0113, 0.0193) = (0.021, 0.063, 0.166)

S_{c7} = (3.437, 4.399, 9.262) × (0.0072, 0.0113, 0.0193) = (0.025, 0.05, 0.179)

These fuzzy values are compared by using Eq. (9-10) and these values are obtained:

$V(S_{c1} \geq S_{c2}) = 1$ $V(S_{c1} \geq S_{c3}) = 1$
$V(S_{c1} \geq S_{c4}) = 1$ $V(S_{c1} \geq S_{c5}) = 1$
$V(S_{c1} \geq S_{c6}) = 1$ $V(S_{c1} \geq S_{c7}) = 1$

$V(S_{c2} \geq S_{c1}) = 0.84$ $V(S_{c2} \geq S_{c3}) = 0.99$
$V(S_{c2} \geq S_{c4}) = 1$ $V(S_{c2} \geq S_{c5}) = 1$
$V(S_{c2} \geq S_{c6}) = 1$ $V(S_{c2} \geq S_{c7}) = 1$

$V(S_{c3} \geq S_{c1}) = 0.83$ $V(S_{c3} \geq S_{c2}) = 1$
$V(S_{c3} \geq S_{c4}) = 1$ $V(S_{c3} \geq S_{c5}) = 1$
$V(S_{c3} \geq S_{c6}) = 1$ $V(S_{c3} \geq S_{c7}) = 1$

$V(S_{c4} \geq S_{c1}) = 0.64$ $V(S_{c4} \geq S_{c2}) = 0.82$
$V(S_{c4} \geq S_{c3}) = 0.82$ $V(S_{c4} \geq S_{c5}) = 1$
$V(S_{c4} \geq S_{c6}) = 1$ $V(S_{c4} \geq S_{c7}) = 1$

$V(S_{c5} \geq S_{c1}) = 0.11$ $V(S_{c5} \geq S_{c2}) = 0.29$
$V(S_{c5} \geq S_{c3}) = 0.31$ $V(S_{c5} \geq S_{c4}) = 0.51$
$V(S_{c5} \geq S_{c6}) = 0.91$ $V(S_{c5} \geq S_{c7}) = 1$

$V(S_{c6} \geq S_{c1}) = 0.19$ $V(S_{c6} \geq S_{c2}) = 0.39$
$V(S_{c6} \geq S_{c3}) = 0.4$ $V(S_{c6} \geq S_{c4}) = 1$
$V(S_{c6} \geq S_{c5}) = 1$ $V(S_{c6} \geq S_{c7}) = 0.61$

$V(S_{c7} \geq S_{c1}) = 0.22$ $V(S_{c7} \geq S_{c2}) = 0.4$
$V(S_{c7} \geq S_{c3}) = 0.41$ $V(S_{c7} \geq S_{c4}) = 0.6$
$V(S_{c7} \geq S_{c5}) = 0.99$ $V(S_{c7} \geq S_{c6}) = 0.92$

Then priority weights are calculated by using Eq. (12):

$d'(A_1)$ = Min (1, 1, 1, 1, 1, 1) = 1
$d'(A_2)$ = Min (0.84, 0.99, 1, 1, 1, 1) = 0.84
$d'(A_3)$ = Min (0.83, 1, 1, 1, 1, 1) = 0.83
$d'(A_4)$ = Min (0.64, 0.82, 0.82, 1, 1, 1) = 0.64
$d'(A_5)$ = Min (0.11, 0.29, 0.31, 0.51, 0.91, 1) = 0.11
$d'(A_6)$ = Min (0.19, 0.39, 0.4, 1, 1, 0.61) = 0.19
$d'(A_7)$ = Min (0.22, 0.4, 0.41, 0.6, 0.99, 0.92) = 0.22

Priority weights form W' = (1, 0.84, 0.83, 0.64, 0.11, 0.19, 0.22) vector. After these values have been normalized, priority weights respect to main goal are computed as (0.261, 0.219, 0.217, 0.167, 0.029, 0.05, 0.057).

The calculation of compare paired alternatives than the noise pollution criteria:

According to the FAHP method, firstly synthesis values must be calculated. From Table 4, these values, respect to main goal, are calculated, as mentioned in Eq. (4-7):

$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1}$ = (0.0044, 0.0072, 0.0102)

$S_i = \sum_{j=1}^{m} M_{gi}^{j} \times \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1}$

S_1 = (9.12, 9.14, 25.21) × (0.0044, 0.0072, 0.0102) = (0.04, 0.066, 0.257)

S_2 = (8.45, 9.14, 23.21) × (0.0044, 0.0072, 0.0102) = (0.037, 0.066, 0.237)

S_3 = (7.78, 9.14, 21.21) × (0.0044, 0.0072, 0.0102) = (0.034, 0.066, 0.216)

S_4 = (7.11, 9.14, 19.21) × (0.0044, 0.0072, 0.0102) = (0.031, 0.066, 0.196)

S_5 = (6.44, 9.14, 17.21) × (0.0044, 0.0072, 0.0102) = (0.028, 0.066, 0.176)

S_6 = (39.48, 56.99, 69.48) × (0.0044, 0.0072, 0.0102) = (0.174, 0.41, 0.709)

S_7 = (5.82, 9.26, 15.35) × (0.0044, 0.0072, 0.0102) = (0.026, 0.067, 0.157)

S_8 = (5.15, 9.27, 13.41) × (0.0044, 0.0072, 0.0102) = (0.023, 0.067, 0.137)

S_9 = (4.48, 9.27, 11.41) × (0.0044, 0.0072, 0.0102) = (0.02, 0.067, 0.116)

S_{10} = (3.75, 9.11, 9.14) × (0.0044, 0.0072, 0.0102) = (0.017, 0.066, 0.093)

These fuzzy values are compared by using Eq. (9-10) and these values are obtained:

$V(S_{c1} \geq S_{c2}) = 1$ $V(S_{c1} \geq S_{c3}) = 1$
$V(S_{c1} \geq S_{c4}) = 1$ $V(S_{c1} \geq S_{c5}) = 1$
$V(S_{c1} \geq S_{c6}) = 0.19$ $V(S_{c1} \geq S_{c7}) = 1$
$V(S_{c1} \geq S_{c8}) = 1$ $V(S_{c1} \geq S_{c9}) = 1$

$V(S_{c1} \geq S_{c10}) = 1$

$V(S_{c2} \geq S_{c1}) = 1$ $V(S_{c2} \geq S_{c3}) = 1$
$V(S_{c2} \geq S_{c4}) = 1$ $V(S_{c2} \geq S_{c5}) = 1$
$V(S_{c2} \geq S_{c6}) = 0.15$ $V(S_{c2} \geq S_{c7}) = 1$
$V(S_{c2} \geq S_{c8}) = 1$ $V(S_{c2} \geq S_{c9}) = 1$
$V(S_{c2} \geq S_{c10}) = 1$

$V(S_{c3} \geq S_{c1}) = 1$ $V(S_{c3} \geq S_{c2}) = 1$
$V(S_{c3} \geq S_{c4}) = 1$ $V(S_{c3} \geq S_{c5}) = 1$
$V(S_{c3} \geq S_{c6}) = 0.11$ $V(S_{c3} \geq S_{c7}) = 0.99$
$V(S_{c3} \geq S_{c8}) = 0.99$ $V(S_{c3} \geq S_{c9}) = 0.99$
$V(S_{c3} \geq S_{c10}) = 1$

$V(S_{c4} \geq S_{c1}) = 1$ $V(S_{c4} \geq S_{c2}) = 1$
$V(S_{c4} \geq S_{c3}) = 1$ $V(S_{c4} \geq S_{c5}) = 1$
$V(S_{c4} \geq S_{c6}) = 0.06$ $V(S_{c4} \geq S_{c7}) = 0.99$
$V(S_{c4} \geq S_{c8}) = 0.99$ $V(S_{c4} \geq S_{c9}) = 0.99$
$V(S_{c4} \geq S_{c10}) = 1$

$V(S_{c5} \geq S_{c1}) = 1$ $V(S_{c5} \geq S_{c2}) = 1$
$V(S_{c5} \geq S_{c3}) = 1$ $V(S_{c5} \geq S_{c4}) = 1$
$V(S_{c5} \geq S_{c6}) = 0.01$ $V(S_{c5} \geq S_{c7}) = 1$
$V(S_{c5} \geq S_{c8}) = 0.99$ $V(S_{c5} \geq S_{c9}) = 0.99$
$V(S_{c5} \geq S_{c10}) = 1$

$V(S_{c6} \geq S_{c1}) = 1$ $V(S_{c6} \geq S_{c2}) = 1$
$V(S_{c6} \geq S_{c3}) = 1$ $V(S_{c6} \geq S_{c4}) = 1$
$V(S_{c6} \geq S_{c5}) = 1$ $V(S_{c6} \geq S_{c7}) = 1$
$V(S_{c6} \geq S_{c8}) = 1$ $V(S_{c6} \geq S_{c9}) = 1$
$V(S_{c6} \geq S_{c10}) = 1$

$V(S_{c7} \geq S_{c1}) = 1$ $V(S_{c7} \geq S_{c2}) = 1$
$V(S_{c7} \geq S_{c3}) = 1$ $V(S_{c7} \geq S_{c4}) = 1$
$V(S_{c7} \geq S_{c5}) = 1$ $V(S_{c7} \geq S_{c6}) = 0$
$V(S_{c7} \geq S_{c8}) = 1$ $V(S_{c7} \geq S_{c9}) = 1$
$V(S_{c7} \geq S_{c10}) = 1$

$V(S_{c8} \geq S_{c1}) = 1$ $V(S_{c8} \geq S_{c2}) = 1$
$V(S_{c8} \geq S_{c3}) = 1$ $V(S_{c8} \geq S_{c4}) = 1$
$V(S_{c8} \geq S_{c5}) = 1$ $V(S_{c8} \geq S_{c6}) = 0$
$V(S_{c8} \geq S_{c7}) = 1$ $V(S_{c8} \geq S_{c9}) = 1$
$V(S_{c8} \geq S_{c10}) = 1$

$V(S_{c9} \geq S_{c1}) = 1$ $V(S_{c9} \geq S_{c2}) = 1$
$V(S_{c9} \geq S_{c3}) = 1$ $V(S_{c9} \geq S_{c4}) = 1$
$V(S_{c9} \geq S_{c5}) = 1$ $V(S_{c9} \geq S_{c6}) = 0$
$V(S_{c9} \geq S_{c7}) = 1$ $V(S_{c9} \geq S_{c8}) = 1$
$V(S_{c9} \geq S_{c10}) = 1$

$V(S_{c10} \geq S_{c1}) = 1$ $V(S_{c10} \geq S_{c2}) = 1$
$V(S_{c10} \geq S_{c3}) = 1$ $V(S_{c10} \geq S_{c4}) = 1$
$V(S_{c10} \geq S_{c5}) = 1$ $V(S_{c10} \geq S_{c6}) = 0$
$V(S_{c10} \geq S_{c7}) = 0.99$ $V(S_{c10} \geq S_{c8}) = 0.99$
$V(S_{c10} \geq S_{c9}) = 0.99$

Then priority weights are calculated by using Eq. (12):

$d'(A_1) = Min\ (1, 1, 1, 1, 0.19, 1, 1, 1, 1)$
$d'(A_2) = Min\ (1, 1, 1, 1, 0.15, 1, 1, 1, 1)$
$d'(A_3) = Min\ (1, 1, 1, 1, 0.11, 0.99, 0.99, 0.99, 1)$
$d'(A_4) = Min\ (1, 1, 1, 1, 0.06, 0.99, 0.99, 0.99, 1)$
$d'(A_5) = Min\ (1, 1, 1, 1, 0.01, 0.99, 0.99, 0.99, 1)$
$d'(A_6) = Min\ (1, 1, 1, 1, 1, 1, 1, 1, 1)$
$d'(A_7) = Min\ (1, 1, 1, 1, 1, 0, 1, 1, 1)$
$d'(A_8) = Min\ (1, 1, 1, 1, 1, 0, 1, 1, 1)$
$d'(A_9) = Min\ (1, 1, 1, 1, 1, 0, 1, 1, 1)$
$d'(A_{10}) = Min\ (1, 1, 1, 1, 1, 0, 0.99, 0.99, 0.99)$

Priority weights form $W' = (0.19, 0.15, 0.11, 0.06, 0.01, 1, 0, 0, 0, 0)$ vector. After these values have been normalized, priority weights respect to main goal are computed as (0.125, 0.99, 0.072, 0.039, 0.007, 0.658, 0, 0, 0, 0).

Ultimately, total weight of each alternative is calculated as sum of achieved values from multiplying the weight of each criterion by alternatives scores. The final scores of alternatives influencing pre-mature closure of Angouran mine are subsequently chosen and ranked as pollution due to heavy metals, the presence of pyrite in the tailing and waste dumps, and sediment of chemical with scores of 0.22, 0.21 and 0.15 respectively, shown in Fig. 5.

Therefore, particular attention should be paid and protective measures should be taken to manage these factors appropriately.

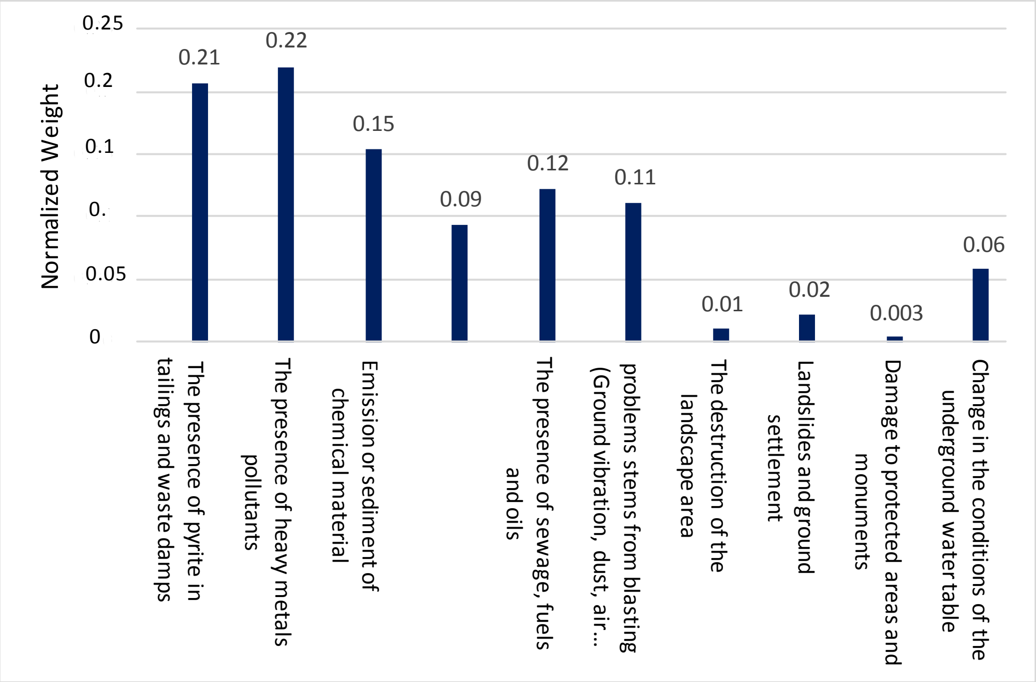

***Figure 5**: The final scores of environmental factors affecting premature mine closure for priority of consideration in the Anguran mine site*

5. Discussions

Mining is a temporary land use that can produce great economic value from a small physical footprint, although sometimes with an environmental and social footprint that can be devastated by the activity. Nevertheless, mining has the potential to create a foundation for real (sustainable) development in the locality and region around the mine [70].

The investigations on environmental issues in the mining have become important fields among researchers during the last decade [13]. Although the positive aspects of mining operation have been mentioned in various studies [71, 72, 73], the topic of ‘sustainable mining’ still seems to be rather controversial [13]. In this regard, it is believed that mining sector has less contribution to sustainable development due to limited reserves [2]; thus, the access of next generation will reduced [74]. In addition, petroleum and mining industries have contributed to adverse environmental impacts over the last 40 years, rising public concerns [75].

Other researchers state that mining activities play a vital role in surroundings and local business [76, 77, 78]. Morphological changes in the disturbed areas, dust, noise, and surface and groundwater contamination are the main environmental hazards caused by mining sector which can lead to pre-mature mine closure. The aim of sustainable development is to reconcile current requirements for socio-economic development with management of a stable global environment and thus ensure a balanced social and environmental legacy for future generations. While a robust and sustainable ecosystem can survive short-term and local environmental pressures during resource exploitation, the long-term goal must be minimal environmental impact and restoration of any imbalances, wherever possible. During mining operations for example, it is very difficult to avoid having some impact on the quality of the local environment. The very nature of mining also makes virtually impossible to perfectly restore the mine site to its previous state, but with careful landscaping and removal or stabilization of potential physical and chemical hazards, it is possible to establish a diverse and functional ecosystem and plan options for post-closure land use [65].

In terms of sustainability from a social perspective, mining operations can clearly be beneficial over the long-term in supporting skills and services, at least in proximity to the mine and potentially over a wider area as well. However, ensuring the future stability and well-being of a community (largely dependent upon mining) after operations cease, requires careful planning and evaluation of options well in advance of mine closure. With these caveats in mind, the overall effect of mining over the long-term may be argued as bringing a net benefit in terms of community stability and prosperity and thus satisfies many sustainable development criteria. However, attainment of a sustainable solution still requires effective response to and management of these issues [65].

Regarding the findings, three factors of the presence of heavy metals pollutants, the presence of pyrite in the tailings and waste dumps, and emission or sediment of chemicals can lead to the acid generation, water pollution (groundwater, surface, downstream), air pollution and threatened local agriculture, ecosystems and residential areas. Appropriate protective measures should be considered to prevent these pollutions and threats. Although the other factors with lower weights are not as important as the first three factors, they need to be noticed and managed properly to avoid pre-mature closure of Angouran mine.

Presence of cyanide and radioactive materials, with a score of 0.09, is not a priority to be treated due to the absence of cyanide at the processing plant as well as mine site. Since we tried to outline the selection process of closure factors for an open-pit mine, in general, we take it into consideration. With respect to the case study, this factor reached a point according to experts' opinion who they were not from Angouran mine. This score stems from pair-wise comparison among major and general mine closure factors including hazardous materials.

6. Conclusions

Mine closure is considered the last and final phase of mine planning and design. Mines close when their deposits are totally excavated, but some factors could result in pre-mature closure such as environmental, economic, social, technical, political and etc. factors. Among them, environmental factors play a crucial role in pre-mature closure of a mine. Hence, these factors should be determined and managed appropriately. The aim of this research is to apply Fuzzy Analytical Hierarchy Process (FAHP) as a powerful tool and a Multiple Criteria Decision Making (MCDM) approach for selecting and prioritizing the major environmental factors affecting pre-mature closure of an open-pit mine; with that regard a case study was conducted in Angouran open pit lead and zinc mine. Results achieved from the analyses demonstrated that factors including pollution due to heavy metals, the presence of pyrite in the tailings and waste dumps, and sediment of chemicals with the scores of 0.22, 0.21 and 0.15, respectively, found as major factors leading to pre-mature mine closure. Therefore, particular attention should be paid and protective measures need to be taken to manage these factors appropriately.

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