Environ Geol (2009) 58:205–216
DOI 10.1007/s00254-008-1509-4

ORIGINAL ARTICLE

Environmental impact assessment of open pit mining in Iran

M. Monjezi · K. Shahriar · H. Dehghani · F. Samimi Namin

Received: 10 November 2007 / Accepted: 4 August 2008 / Published online: 26 August 2008

Abstract Mining is widely regarded as having adverse effects on environment of both magnitude and diversity. Some of these effects include erosion, formation of sinkhole, biodiversity loss and contamination of groundwater by chemical from the mining process in general and open-pit mining in particular. As such, a repeatable process to evaluate these effects primarily aims to diminish them. This paper applies Folchi method to evaluate the impact of open-pit mining in four Iranian mines that lacked previous geo-environmental assessment. Having key geologic resources, these mines are: Mouteh gold mine, Gol-e-Gohar and Chogart iron mines, and Sarcheshmeh copper mine. The environmental components can be defined as public health and safety, social relationships, air and water quality, flora and fauna hence, various impacting factors from the mining activities were estimated for each environmental component. For this purpose, each impacting factor was first given a magnitude, based solely on the range of possible scenarios. Thereafter, a matrix of weighted factors was derived to systematically quantify and normalize the effects of each impacting factor. The overall impact upon each individual environmental component was then calculated by summing the weighted rates. Here, Folchi method was applied to evaluate those environmental conditions. Based on the acquired results, the present paper finally concludes that amongst four case histories in Iran, Sarcheshmeh copper mine significantly affects the environment, with critical level of air pollution there.

Keywords Environmental effects · Open pit mines · Folchi method · Gol-e-Gohar mine · Chogart mine · Sarcheshmeh mine · Mouteh mine

Introduction

The rapid growth of population along with the increased capacity of extracting natural resources around the globe has contributed in endangering the environment. As a matter of fact, due to growing mining activities, attention to the environmental problems and controlling pollution becomes unavoidable. Environmental protection therefore, is one of the most important issues in the sustainable development of a country. Currently, there are no limitations to the capacity of mine production but it is, however, necessary to maintain a suitable condition for miners as well as the general public (Chakraborty et al. 2002; Tadesse 2000).

Mining and related industries have a long recorded history in Iran. A variety of mines exists in the country, some of which date back several thousand years. Mining in Iran can be divided into two periods: unscientific and scientific. In this regard, the year 1847 can be regarded as a turning point from unscientific to scientific and systematic

M. Monjezi (✉)
Faculty of Engineering, Tarbiat Modares University, Tehran, Iran
e-mail: monjezi@modares.ac.ir; monjezi.masoud@gmail.com

K. Shahriar · H. Dehghani
Faculty of Mining and Metallurgical Engineer, Amirkabir University of Technology, Tehran, Iran
e-mail: k.shahriar@aut.ac.ir

H. Dehghani
e-mail: dehghan@aut.ac.ir

F. Samimi Namin
Faculty of Engineering, Zanjan University, Zanjan, Iran
e-mail: farhad_s_n@aut.ac.ir

extraction of ore (Pezeshkan et al. 2005). Recently, much attention has been paid on the mine engineering in Iran due to diversity and abundance of minerals such as, iron, lead, zinc, chromites and variety of building stones across the country.

At present, Iranian mines are owned by both the private and the public (governmental) sectors. Generally, the private sector-controlled mines are smaller in size and pose little environmental hazards compared to the government-controlled mines, which are much larger and often require a processing plant especially for copper, gold, lead, zinc etc. The ore processing could prove more harmful to the environment than ore extraction itself (Sare et al. 2001; Driussi and Jansz 2006; Bozkurt et al. 2008; Hansen et al. 2008). Therefore, scientific and engineering studies are essential to assess the environmental impacts and develop methods to reduce or control them.

Various studies have been conducted so far on the devastating effects of mining on the environment and the ways to assess them. Some of those researcher are: White (1991), Pain et al. (1998), Tadesse (2000), Gobling (2001), Haupt et al. (2001), Blodgett and Kuipers (2002), Folchi (2003). In due course, Gobling used an entropy method to evaluate the environmental impact of a copper mill plant. Blodgett and Kuipers studied the effect of mining on both surface and groundwater reservoirs. By examining the clay-rich mine tailings, Krekeler et al. (2007) explored the environmental and economic impact of the phosphate ore processing. According to Younger et al. (2005), in environmental management, socio-economic issues in the form of improving public perceptions are just as important as scientific investigations. Hamilton (2000) used a database to identify the unusual and unexpected concentrations of elements in the mine tailings. His procedure for environmental assessment was based on identification of exposure levels of elements which are considered safe as well as those known to be hazardous to the environment. Hancock and Turley (2006) used numerical modeling to design a proposed waste-rock dump. Marescotti et al. (2008) calculated active acid mine drainage (AMD) of open-air tailing and waste-rock dumps from the Libiola mine, using the Maximum Potential Acidity, the Acid Neutralizing Capacity and the Net Acid Producing Potential. Smith and Williams (1996a, b; parts I & II) concluded that Geostatistical and Indicator Kriging (IK) techniques can be used effectively to identify metal concentrations in mine waste sites. Assessment of the amount of pollutants in soil drainage can be made by estimating the amount of drainage passing through the soil bottom during a given a time period. This estimation can be a stochastic model (Fernández-Gálvez et al. 2007). The pseudo-total metal concentrations and the potential mobile fractions of metals may serve as a preliminary evaluation of risks posed by contaminated soil from an abandoned uranium mine (Pereira et al. 2008). Antunes et al. (2008) performed an environmental risk assessment by categorizing soils based on their toxicity profiles. The above investigations are very useful however often approach through limited aspects of environmental impact.

With the exception of the Folchi technique, existing evaluation methods are limited in scope, with just one or two aspects of environmental impacts of mining and ore processing. Folchi method simultaneously evaluate many environmental impacts of mining operations i.e. ground vibration, fly rock, air blast (Jimeno et al. 1995), water/air pollution etc. Collection and monitoring of data is also simple for this method.

The Folchi method is being widely used in Italy. Some recent examples include its use at a limestone quarry close to Paitone in Brescia in 2004, a limestone quarry of Sossana in Vicenza in 2001, and a basalt quarry in Orvieto, Terni in 2003. In the 1990s, the technique was applied to a dam excavation inside a park of Orgosolo in Sardinia, a 1,000 m deep mineral water reservoir and related thermal bath complex of Capoportiere in Latina and the construction of a 1,000 m long viaduct in Matera. Additional work in the 1990s included the demolition of a radiation contaminated 100 m high chimney in the decommissioning of a nuclear power plant of Garigliano in Caserta, and construction of two urban waste composting plants as well as an urban waste dump in Latina.

So far, a comprehensive study using the Folchi method has not been conducted for the Iranian mines. Consequently, the present paper tries to apply the Folchi method in order to assess the environmental impacts of four important Iranian mines i.e. Sarcheshmeh copper mine, Chogart iron mine, Mouteh gold mine and Gol-e-Gohar iron mine. The criteria for selecting these mines include their proximity to the residential areas, placement in environmentally and ecologically protected areas, number of people employed, economic importance, mine size and production.

The environmental impact of mining operations

The effects of open-pit mining and mineral processing plants on the environment include land degradation, noise, dust, poisonous gases, pollution of water, etc. (Dudka and Adriano 1997). Figure 1 shows typical pathways of common pollutant transfer from a tailing dam or from a processing plant to a river if the waste management is not efficient. If there is no impermeable layer, below the deposit, the infiltration of meteoric precipitation through deposit can transfer the pollutant(s) via groundwater flow. The extraction process could itself modify the water flow

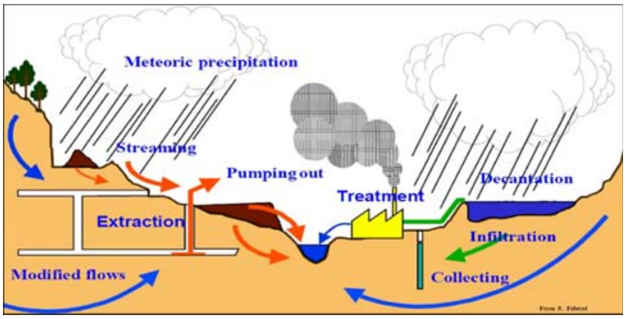

Fig. 1 Pollutant transfer (Charbonnier 2001)

and accelerate this transfer. Infiltration may also occur below a decantation basin (Charbonnier 2001).

The above activities may change the topography and vegetation, as well. From the noise and vibration point of view, drilling and blasting operations as well as application of heavy vehicles, crushers, and mills are very important (Ashtiani 2005).

Blasting, haulage and transportation are the main reasons for the dust however, it may be produced in nearly all the phases of the processing plant, from the beginning point (crusher) to the end (drying of ore concentration) (Rawat 2003; Shu et al. 2001).

Water pollution is another aspect of mine operations greatly impacting the environment (Fernández-Gálvez et al. 2007; Jordanov et al. 2007; Casiot et al. 2007; Shikazono et al. 2008; Chalupnik and Wysocka 2008). If a springhead is situated in the mine area, the pollution endangers springs existed in the area (Blodgett and Kuipers 2002). Similarly, the contaminated water in the mining operation has vital impacts on the rivers, agriculture, fresh drinking waters and ecosystems, because of abundance of heavy metals, suspended solid particles and decreasing level of pH. Decreasing water level in the mines due to drainage not only causes undesirable changes in the nearby lakes but it can also threat the aquatics (Ritcy 1989; Baker and Amacher 1982). The main reason of environment pollution of the fresh water is acidic water, draining from mines (Shu et al. 2001).

Mining operations with degradation of the land largely contribute to the corrosion of soil—a phenomenon that can be seen more in the surface mining activities (Sengupta 1993).

Mine waste can be defined as part of the materials resulting from the exploration, mining and processing of substances governed by legislation on mines and quarries. It may consist of natural materials without any modification other than crushing (ordinary mining waste, unusable mineralized materials), processed to varying degrees during the ore-dressing and enrichment phases, and possibly containing chemical, inorganic and organic additives. As overburden and topsoil are classified as waste (Charbonnier 2001), the characteristics of such spoil could be variable and are influenced by the minerals and process methods involved the specific environmental situation, and the type of dumping and alteration.

Much of the mine wastes has high concentration of heavy metals and toxic materials like lead, copper, zinc, aluminum, mercury, marcasite and pyrite (FeS_2), which are harmful for the environment (Gang and Langmuir 1974; Barnes 1979; Daskalakis and Helz 1999). Specifically, wastes containing pyrite have the potentials of creating dangerous AMD.

Pyrite is a common sulfide, often associated with valuable minerals in the mines. At the same time, in non-ferrous metal mines, pyrite is separated as a gangue mineral from the valuable metals through physical separation techniques like froth flotation, and then disposed into tailing ponds or dams as a waste (Petruk 2000; Wills 2006). As a matter of fact, the air-oxidation of pyrite in the tailing pond creates acid mine.

A few minerals including pyrite can be described as salts with weak bases and strong acids. They chiefly result from the oxidation of pyrite or marcasite (FeS_2) exposed in the mining of mineral deposits and coal. Such acid minerals, which are dominantly Fe^{3+} sulfates and to a minor extent Al^{3+} sulfates, typically appear from the evaporation of pooled acid-mine waters or of the moisture in unsaturated mine wastes or spoils that contain the sulfides (Langmuir 1997; Berner and Berner 1987). Acid mine drainage (AMD) from mine wastes can interact with natural carbonates, salts, and induce variation in the pH levels in natural waters (Granger and Warren 1969; Holland 1978; Boulegue and Michard 1979; Faure 1991; Shahriar and Samimi Namin 2007). Jha et al. (2008) proposed carrier-micro encapsulation (CME) as a method to suppress both the floatability and oxidation of pyrite. In this method, pyrite is coated with a thin layer of metal oxide or hydroxide using catechol solution as a carrier combined with metal ions. The layer converts the pyrite surface from hydrophobic to hydrophilic and thus, acts as a protective coating against oxidation. Shin et al. (2008) used activated carbon to absorbent AMD. Anoxic limestone drains (ALDs) represent a well-established low cost passive treatment alternative for neutralizing AMD (Hedin and Watzlaf 1994; Taylor and Waters 2003; Cravotta 2003; Kalin et al. 2006). Such drains, in their simplest form, are merely basins or trenches filled with limestone through which, the AMD is pumped or drained. The anoxic (i.e. reducing) state of the ALDs is required to prevent dissolved ferrous iron from oxidizing and subsequently precipitating within the bed as ferric hydroxide. Reducing conditions are usually ensured by isolating the system from the atmosphere and incorporating a reducing agent, e.g. organic material or scrap iron (Kleiv and Thornhill 2008).

Compare to the underground mining, it can be said that open-pit mining has more of a negative impact (Zhong 1998). Therefore, it is necessary to study the pollution mechanism and develop technologies to address problems affecting the environment.

Folchi method for open-pit mining

The Folchi method (2003) was first applied for a mining project in the Italian city of Sardina. It is the numerical expression of environmental effect of open pits. This method consists of the following seven stages:

(1) Characterizing the pre-existing environmental context in terms of geology, geotechnics, hydrology, weather, economy, etc., (2) Identifying the impacting factors, which could modify the pre-existing environmental conditions in the mine life, (3) Defining the possible ranges for the magnitude of the variation caused by each impacting factor, (4) Singling out the environmental components whose pre-existing condition could be modified as a result of mining, (5) Correlating each impacting factor and each environmental component, (6) Estimating the specific magnitude for each impacting factor, using the already defined ranges, (7) Calculating the weighted sum of the environmental impact on each environmental component.

In this method, some parameters such as general health and safety, social relationships, weather and climate conditions, vegetation and, animals are defined first, for an area affected by a mining operation. Then, consequences of effective (directly or indirectly) mining indexes on the each of the environmental parameters are determined, by applying a rating system for each parameter, based on various concerned scenarios. The sum of all the ratings of effective parameters determines overall effect on each of the environmental indexes. According to this method, impacting factors are as follows (Folchi 2003):

I. Alteration of area's potential resources; II. Exposition, visibility of the pit; III. Interference with surface water; IV. Interference with underground water; V. Increase in vehicular traffic; VI. Atmospheric release of gas and dust; VII. Fly rock; VIII. Noise; IX. Ground vibration; and X. Employment of local work force.

The possible scenarios for each impacting factor are then considered and a magnitude is given to each of them. Table 1 shows various scenarios and their related magnitudes for each impacting factor.

Site descriptions

The Folchi method was first applied in four important open-pits of Iran namely Sarcheshmeh copper mine, Chogart iron mine, Gol-e-Gohar iron mine and Moutehh gold mine (Fig. 2).

Mouteh gold mine

The Mouteh gold mine is located 295 km Southwest of Tehran, 7 km northwest of Mouteh village in Mimeh town of Isfahan province. The ore deposit is distributed in nine distinct parts, i.e. Chah Khatoun, Senjedeh, Chah Bagh, Tangeh Zar, Seh Calap, Darreh Ashki, Cheshmeh Gohar, Ghorom Ghorom and Chah-e-Allameh, covering a total area of about 150 sq. km. The Mouteh gold deposit belongs to the Precambrian era and is a metamorphic region with mica schist, quartzite, gneiss, biotite, and amphibolite as common lithologies.

The mine is being exploited by open-pit mining. It has mine reserves of approximately 3.5 Mt with an average grade of 2.71 gr/t. The height of benches is 5 m, whereas the angle of overall slopes and slope of working benches are 52° and 65°, respectively. The distance of mine to mill plant is 2–5 km. Figure 3a shows an exterior view of the mine.

Mill plant recovery is 60% with a capacity of 600 t/d. It has four stages of processing, i.e. crushing, grinding, leaching and the gold room. Gold is being processed with cyanide, which is recognized as extremely toxic and damaging pollutant. The tailing dam can be extremely hazardous. As the mine is situated in an environmentally protected area, monitoring and controlling of pollution indexes is a vital task. Figure 3b and c show the processing plant and tailing dam of the Mouteh gold mine, respectively.

Sarcheshmeh copper mine

This mine is situated at 160 km southwest of Kerman, about 50 km south of the city of Rafsanjan in Kerman province and is the largest copper mine in Iran (Fig. 4a). The area belongs to the central part of an elongated NW-SE mountain belt, which is principally composed of folded volcano-sedimentary rocks. The geology of Sarcheshmeh porphyry deposit is very complicated and various rock types can be found there. Mineralization in this deposit is associated with the Late Tertiary, with main minerals being chalcocite, chalcopyrite, covellite, bornite and molybdenite. However, other minerals are also seen in the deposit, which includes molybdenum, gold and silver. The oxide zone of deposit consists mainly of cuprite, tenorite, malachite and azurite. Pyrite is the gangue mineral, which causes acidity of mine sewage. The proven reserve of deposit is approximately 826 Mt with an average grade of 0.7%. This mine is also exploited by open-pit mining, where the height and slope of working benches are 12.5 m

Table 1 Ranges of magnitude for impacting factors

Impacting factors	Scenario	Magnitude
I. Alteration of area's potential resources	Parks, protected areas	8–10
	Urban area	6–8
	Agricultural area, wood	3–6
	Industrial area	1–3
II. Exposition, Visibility of the pit	Can be seen from inhabited areas	6–10
	Can be seen from main roads	2–6
	Not visible	1–2
III. Interference with above ground water	Interference with lakes and rivers	6–10
	Interferences with non relevant water system	3–6
	No interference	1–3
IV. Interference with underground water	Water table superficial and permeable grounds	5–10
	Water table deep and permeable grounds	2–5
	Water table deep and un-permeable grounds	1–2
V. Increase in vehicular traffic	Increase of 200%	6–10
	Increase of 100%	3–6
	No interference	1–3
VI. Atmospheric release of gas and dust	Free emissions in the atmosphere	7–10
	Emission around the given reference values	2–7
	Emission well below the given reference values	1–2
VII. Fly rock	No blast design and no clearance procedures	9–10
	Blast design and no clearance procedures	4–9
	Blast design and clearance procedures	1–4
	Peak air overpressure at 1 km distance	
VIII. Noise	<141 db	8–10
	<131 db	4–8
	<121 db	1–4
IX. Ground vibration	Cosmetic damage, above threshold	7–10
	Tolerability threshold	3–7
	Values under tolerability threshold	1–3
X. Employment of local work force	Job opportunities	
	High	7–10
	Medium	3–6
	Low	1–2

and 62.5°, respectively. The angle of overall slope ranges from 32° to 34°. The distance of crusher to mine is 3 km. The annual capacity of the mill plant is 51,000 tons concentrate with an average grade of 30% and a recovery of 65%. Figure 4b and c illustrate the mill plant and tailing dam in Sarcheshmeh copper mine, respectively.

Chogart iron ore mine

Chogart iron ore mine is situated 12 km northeast of Bafgh, 125 km southeast of the city of Yazd in the Yazd province. The deposit belongs to Cambrian era. There is a large quantity of valuable minerals such as iron, manganese, apatite, lead and zinc in this region. Mine design was initially carried out in 1970, and was based on approximately 134 Mt of mineable ore reserve. This mine is an open pit operation where the height of benches is 12.5 m while the overall pit slope and angle of individual working benches are 50° and 69°, respectively. Mill plant recovery is 70% and the amount of annual concentrate and waste production is 3 and 1.3 Mt, respectively. Electric power consumption of the mill plant is 40 kwh per tone of concentrate. Figure 5 shows an exterior view of the mine site and mill plant in Chogart iron mine.

Gol-E-Gohar iron ore mine

Gol-e-Gohar iron ore mine is located some 55 km southwest of Sirjan in Kerman province. This area is a combination of metamorphic (Paleozoic) and sedimentary

Fig. 2 Location of case study mines in Iran

(Mesozoic) rocks, consisting mostly of gneiss, mica schist, amphibolite, quartz schist and calcite types of rocks. The operation in this mine is also an open pit facility. Here, the height of benches is 15 m, whereas the angle of overall slope and the angle of each working bench are 50° and 70°, respectively. Mill plant recovery is 68%. The capacity of the mill plant is 5 Mt concentrate per year while yearly production of tailings is 1.35 Mt. The electricity consumption for the production of one ton concentrate is 20 kwh. Figure 6a and b show the mine site and mill plant of Gol-e-Gohar iron mine, respectively.

Results

In the present research, the environmental data related to the above four case studies were collected and then using the Folchi method each of the open-pit activities which affect the environment was evaluated. Further, using the magnitude ranges defined in Table 1, each impacting factor of the proposed mining activity was assessed (Table 3). Final scoring for each environmental component can be acquired by multiplying Table 2 into Table 3. For each case study, the overall effect on each environmental component is calculated by summing the weighted magnitudes of all the impacting factors (Tables 4, 5, 6, 7).

The Folchi method indicates that specific aspects of environmental impact can be quantified. The most significant impacts in the Sarcheshmeh copper mine are air quality, above ground and flora and fauna with score values of 100, 80 and 77.6, respectively. In the Mouteh gold mine, environmental components of air quality, economy and use of territory had score values of 80, 70 and 70, respectively. The most affected environmental components in the Gol-e-Gohar iron mine are underground, economy and social relationships with scores of 76.7, 70 and 61.6, respectively. Finally, the most affected environmental components for the Chogart iron mine are economy, social relationships and use of territory with 80, 66.2 and 65.7 score values, respectively (Fig. 7).

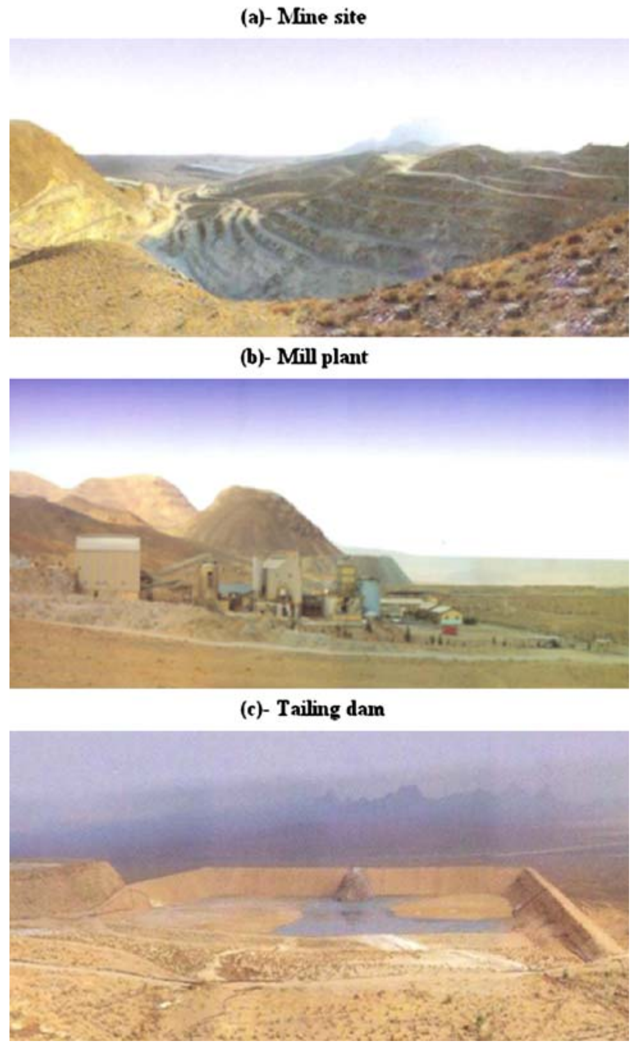

Fig. 3 Mouteh gold mine

Discussion

To compare all the above cases, the sum of scores for all the environmental components can be calculated and then evaluated for each case. The sum of component scores for Sarcheshmeh, Chogart, Gol-e-Gohar and Mouteh mines are 766.5, 625.8, 570.3 and 528.2, respectively. Through this calculation, it can be said that the Sarcheshmeh mine is the most harmful for the environment while the Mouteh mine

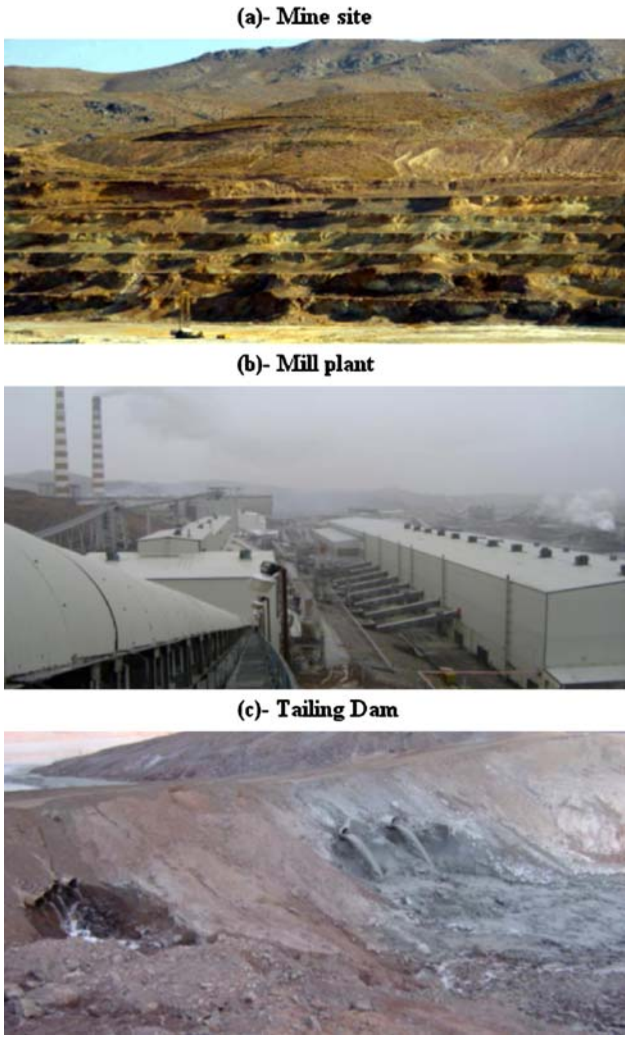

Fig. 4 Sarcheshmeh copper mine

Fig. 5 Mine and mill plant of Chogart iron mine

is the least one. As a matter of fact, some remedial measures must be taken for the affected environmental components (e.g. air quality, water condition, etc.), which are essential for the living creatures. Recently, a plant converting SO_2 to H_2SO_4 has been constructed for the Sarcheshmeh mine which has been seriously affecting the air quality, however, the air pollution is still higher than

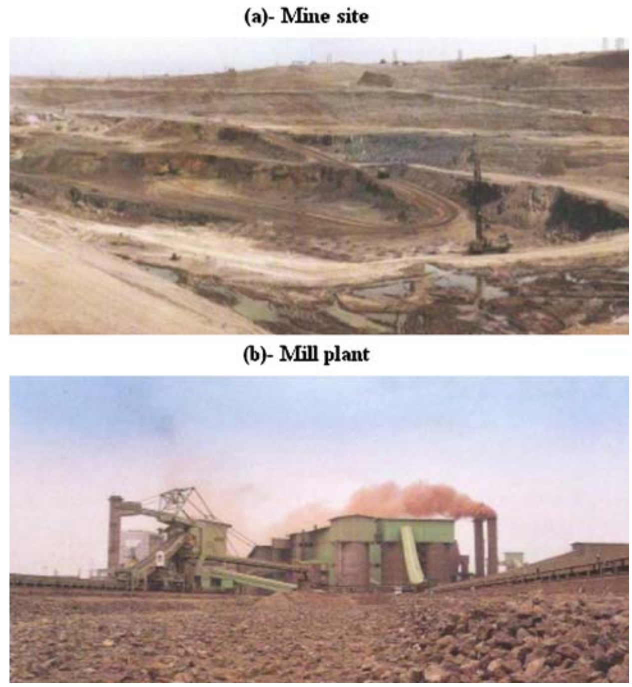

Fig. 6 Gol-e-Gohar iron mine

the standard level. Also, the Sarcheshmeh mine has seriously affected the water quality in the area (Table 5) however; this component is marginal for the other cases. In this regard, the Gol-e-Gohar mine is the least harmful project in the short term consideration. Table 4 shows high ground vibration for Sarcheshmeh, Chogart and Gol-e-Gohar mines for which reducing charge per delay is a logical solution. Precautions should be made to improve air quality at the Mouteh gold mine, which is placed in a protected area.

The Folchi method has accounted many environmental parameters not recognized by other approaches; hence it is the best approach for evaluating mine operations in Iran. This is the first such analysis performed in Iran. With due attention to its usefulness and prevalent environment, the approach could be used for all mines in Iran in particular and the mines in neighboring countries in general. Accordingly, the Folchi method can potentially be used as an environmental regulation tool for Iran. There are several benefits to apply this method e.g. it makes it possible to simplify complex analysis by splitting it in a number of easily quantified components, which can then be handled one by one at a time, being reconstituted in a standardized matrix to give a total magnitude value. This value can then be used to compare mining operations of different types in a consistent manner. This is a key requirement for use as a regulatory tool.

One area of improvement for the Folchi method relates to that fact that the method is a snap shot of

Table 2 Correlation matrix with values of the weighted influence of each impacting factor on each environ component

Impacting factors	Environmental Components										
	Human health and safety	Social relationship	Water quality	Air quality	Use of territory	Flora and fauna	Above ground	Underground	Landscape	Noise	Economy
I. Alteration of area's potential resources	Med	Min	Nil	Nil	Max	Min	Nil	Nil	Max	Nil	Nil
	0.80	0.77	0	0	5.71	0.63	0	0	2.86	0	0
II. Exposition, Visibility of the pit	Nil	Min	Nil	Nil	Med	Nil	Nil	Nil	Max	Min	Nil
	0	0.77	0	0	2.86	0	0	0	2.86	2.00	0
III. Interference with above ground water	Max	Nil	Max	Nil	Nil	Max	Med	Nil	Max	Nil	Nil
	1.60	0	4.44	0	0	2.50	6.67	0	2.86	0	0
IV. Interference with underground water	Min	Nil	Max	Nil	Nil	Nil	Nil	Med	Nil	Nil	Nil
	0.40	0	4.44	0	0	0	0	6.67	0	0	0
V. Increase in vehicular traffic	Max	Max	Nil	Nil	Min	Max	Nil	Nil	Min	Nil	Nil
	1.60	3.08	0	0	1.43	2.50	0	0	0.71	0	0
VI. Atmospheric release of gas and dust	Max	Min	Min	Max	Nil	Max	Min	Nil	Min	Nil	Nil
	1.60	0.77	1.11	10.00	0	2.50	3.33	0	0.71	0	0
VII. Fly rock	Max	Nil	Nil	Nil	Nil	Med	Nil	Nil	Nil	Nil	Nil
	1.60	0	0	0	0	1.25	0	0	0	0	0
VIII. Noise	Med	Max	Nil	Nil	Nil	Min	Nil	Nil	Nil	Max	Nil
	0.80	3.08	0	0	0	0.63	0	0	0	8.00	0
IX. Ground vibration	Max	Med	Nil	Nil	Nil	Nil	Nil	Min	Nil	Nil	Nil
	1.60	1.54	0	0	0	0	0	3.33	0	0	0
X. Employment of local work force	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Max
	0	0	0	0	0	0	0	0	0	0	10.00
Total	10	10	10	10	10	10	10	10	10	10	10

Table 3 Rating of environmental parameters in the case study of mines

Impacting factors	Mouteh	Sarcheshmeh	Chogart	Gol-E-Gohar
I. Alteration of area's potential resources	9	3	7	3
II. Exposition, Visibility of the pit	5	3	5	2
III. Interference with above ground water	3	7	2	3
IV. Interference with underground water	4	7	6	7
V. Increase in vehicular traffic	3	9	8	6
VI. Atmospheric release of gas and dust	8	10	6	5
VII. Fly rock	4	5	5	5
VIII. Noise	1	7	6	7
IX. Ground vibration	1	7	6	9
X. Employment of local work force	7	7	8	7

conditions and thus is temporally limited. Several issues arise as the impacts are to be assessed in a predefined temporal window. Here, only those environmental problems are assessed that are evident at the time of the evaluation. Operators can potentially take action to skew assessment prior to a single evaluation. Incipient environmental issues or issues which have been improved but not fully rectified may be missed. Repeated evaluations over a period of time would make the approach more meaningful. Both scheduled and unannounced site assessments should ideally be made quarterly and annually.

The method in its present form however is not suitable for major accident or catastrophic scenarios in the mines. Moreover, the Flochi method is potential for storage facilities of explosives and agro-chemical facilities, as well. Efforts are also being made to refine and adapt the method to address wider scenarios (R. Folchi, Personal

Table 4 Final scoring for each environmental component in Mouteh gold mine

Impacting factors	Environmental Components										
	Human health and safety	Social relationship	Water quality	Air quality	Use of territory	Flora and fauna	Above ground	Underground	Landscape	Noise	Economy
I. Alteration of area's potential resources	7.2	6.9	0	0	51.4	5.7	0	0	25.7	0	0
II. Exposition, Visibility of the pit	0	3.9	0	0	14.3	0	0	0	14.3	10	0
III. Interference with above ground water	4.8	0	13.3	0	0	7.5	20	0	8.6	0	0
IV. Interference with underground water	1.6	0	17.8	0	0	0	0	26.7	0	0	0
V. Increase in vehicular traffic	4.8	9.2	0	0	4.3	7.5	0	0	2.1	0	0
VI. Atmospheric release of gas and dust	12.8	6.2	8.9	80	0	20	26.6	0	5.7	0	0
VII. Fly rock	6.4	0	0	0	0	5	0	0	0	0	0
VIII. Noise	0.8	3.1	0	0	0	0.6	0	0	0	8	0
IX. Ground vibration	1.6	1.5	0	0	0	0	0	3.3	0	0	0
X. Employment of local work force	0	0	0	0	0	0	0	0	0	0	70
Total	40	30.8	40	80	70	46.3	46.7	30	56.4	18	70

Table 5 Final scoring for each environmental component in Sarcheshmeh copper mine

Impacting factors	Environmental Components										
	Human health and safety	Social relationship	Water quality	Air quality	Use of territory	Flora and fauna	Above ground	Underground	Landscape	Noise	Economy
I. Alteration of area's potential resources	2.4	2.3	0	0	17.1	1.9	0	0	8.6	0	0
II. Exposition, Visibility of the pit	0	2.3	0	0	8.6	0	0	0	8.6	6	0
III. Interference with above ground water	11.2	0	31.3	0	0	17.5	46.7	0	20	0	0
IV. Interference with underground water	2.8	0	31.3	0	0	0	0	46.7	0	0	0
V. Increase in vehicular traffic	14.4	27.7	0	0	12.9	22.5	0	0	6.4	0	0
VI. Atmospheric release of gas and dust	16	7.7	11.1	100	0	25	33.3	0	7.1	0	0
VII. Fly rock	8	0	0	0	0	6.3	0	0	0	0	0
VIII. Noise	5.6	21.6	0	0	0	4.4	0	0	0	56	0
IX. Ground vibration	11.2	10.8	0	0	0	0	0	23.3	0	0	0
X. Employment of local work force	0	0	0	0	0	0	0	0	0	0	70
Total	71.6	72.4	73.3	100	38.6	77.6	80	70	50.7	62	70

Communications, 2008). Broadly speaking, the method seems potential for a number of settings and could be involved in the extraction of various geological resources including petroleum operations.

Conclusions

The Folchi method allows for quantitative analysis of mining activities especially to highlight the environmental

Table 6 Final scoring for each environmental component in Chogart iron mine

Impacting factors	Environmental Components										
	Human health and safety	Social relationship	Water quality	Air quality	Use of territory	Flora and fauna	Above ground	Underground	Landscape	Noise	Economy
I. Alteration of area's potential resources	5.6	5.4	0	0	40	4.4	0	0	20	0	0
II. Exposition, Visibility of the pit	0	3.9	0	0	14.3	0	0	0	14.3	10	0
III. Interference with above ground water	3.2	0	8.9	0	0	5	13.3	0	5.7	0	0
IV. Interference with underground water	2.4	0	26.6	0	0	0	0	40	0	0	0
V. Increase in vehicular traffic	12.8	24.6	0	0	11.4	20	0	0	5.7	0	0
VI. Atmospheric release of gas and dust	9.6	4.6	6.7	60	0	15	20	0	4.3	0	0
VII. Fly rock	8	0	0	0	0	6.3	0	0	0	0	0
VIII. Noise	4.8	18.5	0	0	0	3.8	0	0	0	0	0
IX. Ground vibration	9.6	9.2	0	0	0	0	0	20	0	48	0
X. Employment of local work force	0	0	0	0	0	0	0	0	0	0	80
Total	56	66.2	42.2	60	65.7	54.4	33.3	60	50	58	80

Table 7 Final scoring for each environmental component in Gole-e-Gohar iron mine

Impacting factors	Environmental Components										
	Human health and safety	Social relationship	Water quality	Air quality	Use of territory	Flora and fauna	Above ground	Underground	Landscape	Noise	Economy
I. Alteration of area's potential resources	2.4	2.3	0	0	17.1	1.9	0	0	8.6	0	0
II. Exposition, Visibility of the pit	0	1.5	0	0	5.7	0	0	0	5.7	4	0
III. Interference with above ground water	4.8	0	13.3	0	0	7.5	20	0	8.6	0	0
IV. Interference with underground water	2.8	0	31.3	0	0	0	0	46.7	0	0	0
V. Increase in vehicular traffic	9.6	18.5	0	0	8.6	15	0	0	4.3	0	0
VI. Atmospheric release of gas and dust	8	3.9	5.6	50	0	12.5	16.7	0	3.6	0	0
VII. Fly rock	8	0	0	0	0	6.3	0	0	0	0	0
VIII. Noise	5.6	21.6	0	0	0	4.4	0	0	0	56	0
IX. Ground vibration	14.4	13.9	0	0	0	0	0	30	0	0	0
X. Employment of local work force	0	0	0	0	0	0	0	0	0	0	70
Total	55.6	61.6	50	50	31.4	47.6	36.7	76.7	30.7	60	70

effects of the mining. Going through the four existing mines of Iran, it thus indicates that the Gol-e-Gohar iron mine is the least destructive for the environment while the Sarcheshmeh copper mine is the most one. The method applied in the current research may be an important tool for future environmental regulation development in Iran. The

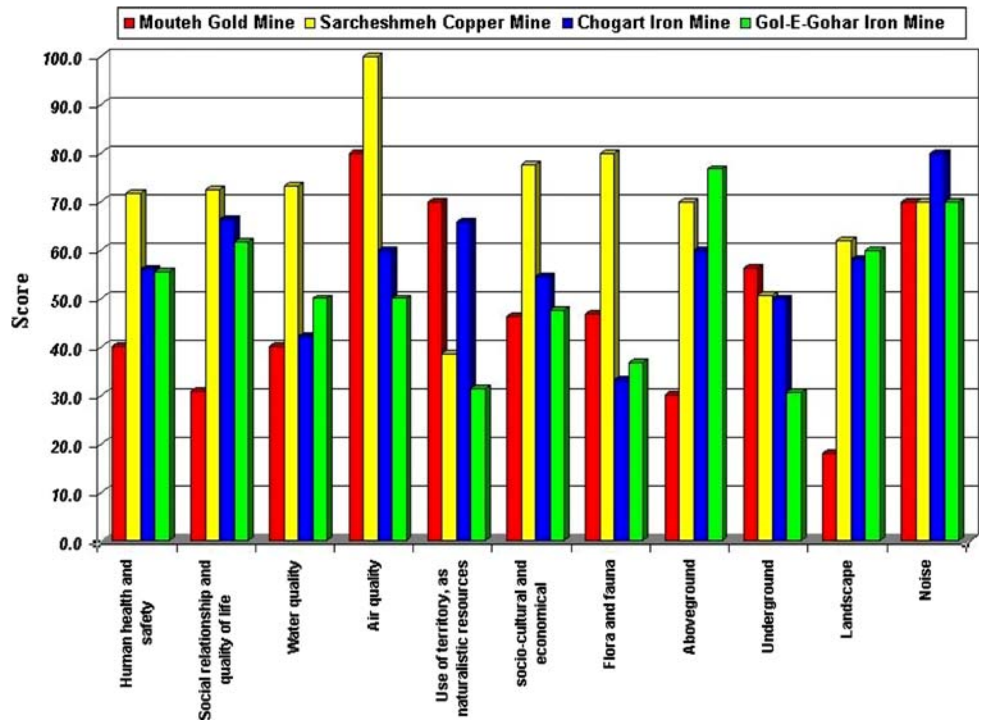

Fig. 7 Comparison between the overall effects on each environmental component related to each mine

approach is also flexible and potentially useful in different settings. The Folchi method may also permit the possibility of fair, repeatable comparisons of environmental assessments of mine operations, globally.

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