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Environmental impact assessment and sustainability level determination in cement plants (Case study: Shahrood cement plant)

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Abstract

Focusing on environmental impact assessment as a new tool to determine the harmful effects of projects on the environment is very necessary. The establishment of cement plants in Iran is accompanied by huge investments that aim to create jobs and have others economic aspects; this trend is on the rise. However, cement plants contribute to environmental pollutions. Therefore, understanding the effect of activities in these potentially polluting centres will greatly help determine future strategies. For the control and prevention of pollution, it is necessary to use a model for the quantitative assessment of environmental impacts. In this study, the Folchi method has been using to recognize and identify environmental pollution by cement plants and effective solutions to decrease the negative impacts of environmental pollution by Shahrood cement plant. According to the results, the contamination generated by the plant, especially for environmental components such as air quality, area landscape, soil of the area, ecology, and area usage are more significant than other environmental components. The EIA results are then obtained and used to assess the sustainability of the complex using Phillips mathematical model. The obtained results indicate that this complex is unsustainable; therefore, preventive environmental activities must be recommended with a preference to reduce environmental damages through its components.

Keywords: *Sustainable development, Environmental Impact Assessment (EIA), Cement industry, Shahrood cement plant, Folchi method, Phillips mathematical model*

1. Introduction

Over the years, industry and technology have improved living standards and raised the level of human knowledge; but they are also associated with destruction and pollution. Humans are the most effective and important factor for making changes in the environment. In order to sustain human life while also creating useful and appropriate changes in the environment, they damage the environment. Thus, pollution is created by humans and has to be managed by humans.

Industrial development and environmental sustainability are two basic elements in development planning. For sustainable development, industrial development must be based on the concept of environmental sustainability. The environment is a key element in the sustainable development of each country. The lack of attention to environment issues and natural resources has worrisome implications. These days, environmental impact assessment (EIA) for industrial and mining activities is necessary for preventing and controlling environmental problems. In fact, the purpose of the EIA programme is to identify the harmful effects of an industrial or mining activity and all aspects affected by them in order to reduce long-term effects. Sustainable development conception in the industries, especially the mining industry, was studied by researchers in the early 1990s (National Academy of Sciences 1996). Many researchers, such as Von Below (1993), state that the continuous exploration of minerals, technological innovations, and environmental remediation are in line with the sustainable development of mining. Allan (1995) also has a similar opinion and states that mining is sustainable when the rate of use of minerals does not exceed the total discovered new resources and recoverable materials.

Another important issue associated with sustainable development is the exploitation and utilization of non-renewable resources. Crowson (1998) claims that if a mine is considered from a resource exhaustion aspect only, no operation can be sustainable. Worrall et al. (2009) also believe that all mineral resources are limited and non-renewable over time. Therefore, mining operations are fundamentally unsustainable due to the limited resources of the earth. According to Richards (2009), no mine can last forever. It is a fact that mineral development will end sometime. This would make the integration of the sustainability considerations into the

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mining process highly appropriate. However, mining can be sustainable if it is conducted in a mode that balances the economic, environmental, and social considerations.
According to the 'Mining, minerals, and sustainable development' (MMSD) project undertaken in 2002, sustainable developments in mining maximizes the welfare of the present generation in such a way that the benefits and costs are fairly distributed without compromising the ability of the future generations to meet their own needs (IIED and WBCSD 2002). Basu and Kumar (2004) state that achieving sustainable developments in mining requires good governance, as the foundation of sustainable development is based on the interaction with project stakeholders. According to Eggert (2006), environmental protection, social justice, and economic growth are vital for achieving sustainable development of mining. According to McCullough and Lund (2006), the mining industry has worked towards reducing its operational risks and maintaining its social license to extract resources through multiple strategies. These are focused around the concept of sustainable developments through the creation of sustainable livelihoods (employment, community development, and infrastructure), resource optimization, and minimization of environmental and social impacts after mine closure.
A major weakness associated with sustainability interpretation is that this term is often used in an interchangeable manner with 'environmental management' and 'environmental protection'. Therefore, several assessments have focused on environmental protection with little mention of the socio-economic issues. Recent advances in EIA methods have yielded more quantitative assessment to determine the impacts of mining operations (Yu et al. 2005; Vatalis and Kaliampakos 2006; Sarkar et al. 2007; Si et al. 2010). However, EIA can be used to assess all issues related to sustainable development (Ataei et al. 2016). Various methods of EIA include (Folchi 2003) matrices, networks, checklists, multi-criteria decision-making methods, input-output analysis, lifecycle assessment (LCA), fuzzy sets, rapid impact assessment matrix (RIAM), etc. One of the most important tools for EIA is the Folchi method. This method is a subset of the matrices method. This method can review many environmental impacts in a complex at the same time, while other methods are able to review only one or two aspects of the environmental impacts.
The main objectives and benefits of EIA are as follows (Jarvis and Younger 2000):
• Prevention of the destructive effects of industrial and mining activities and increasing the environmental quality.
• Compliance with laws and environmental standards at all stages of the mine lifecycle.
• Creation of awareness and knowledge about the importance of environmental issues in project management.
• Determining the potential consequences and effects through quantitative and qualitative assessment methods.
• Offering suggestions for the reduction of pollution of natural resources and establishment of appropriate planning.
• Fixed community dissatisfaction.
• Elimination of inconsistencies between the people and the government.
• Link creation between conservation and development, etc.
Some of the projects subjected to EIA are refinery and petrochemical plants, power plants, steel industries, dams, airports, agro-industrial units, large industrial slaughterhouses, industrial waste recycling centres, oil and gas pipeline plans, fuel storage projects, highway and railway plans and projects, natural tourism project, coast projects, mining activities, cement plants, sugar plants, etc.
Cement manufacturing is one of the major factors causing pollution. If these plants fail to comply with standards, they will be the most polluting plants. The establishment of cement plants in Iran is accompanied by huge investments that aim to create jobs and have others economic aspects; this trend is increasing. However, cement plants contribute to environmental pollution, including pollution of the air and water, loss of vegetation cover, etc.
Nowadays, the focus and concern of human societies are environmental protection and environmental standards, in order to sustain human life, which is a serious requirement. Obviously, in such a situation, one of the main concerns of cement industry and other such industries should be environmental protection and their role in sustainable development.
Cement production units are a major industry in every country. These units are the basis of development, as cement is an important and strategic commodity and is the most important construction materials. Targeted increase in the pace of development of construction activity in the world has led to an increased number of cement plants, as well as a change in a greater breadth of the ecosystem. The cement industry, due to the nature of its activities, is one of the industries with the most impact on the environment. Initially, this industry only faced the problems of dust and its effects, but about half a century ago, the effects of noise, vibration, and specific exhaust emissions such as sulphur dioxide, nitrogen oxides, and carbon dioxide from cement kiln started being considered. These factors, in some cases, can have destructive impacts on the environment. It was also found that excessive concentrations of toxic heavy metals may also be present in the emissions from cement kilns.
In Iran, the environmental impact of cement plants is a controversial and serious subject. Cement plants have different problems, some of which are as follows:

• Unsuitability of the location of most of the country's cement plants.
• Output smokestack height in these units is not balanced according to the weather and climate conditions.
• Depreciable technology in most of the cement plants leads to release of excessive particles to the environment.
• Use of heavy fuels containing sulphur is above the permissible standard levels.
• The high level of fuel consumption in these plants due to depreciable technology.
• Lack of standard energy consumption in cement plants.

The above text indicates that it is necessary to identify appropriate ways to control and reduce the effects of pollution by cement plants. The aim of this work is to assess the sustainability of cement plants through the EIA. Thus, in the first step of this study, the causes of environmental pollution and the harmful effects of pollution by cement plants were identifying and the important influencing factors and environmental components were determined. Then, by using the method developed by Folchi (2003) - one of the most important methods in EIA- these risks were identified and evaluated in the Shahrood cement plant. Afterwards, the obtained EIA results were used to assess the level and nature of the complex sustainability using the Phillips mathematical model. This model can define sustainability, the parameters and constraints of the key components, and the conditions in which sustainability or unsustainability can occur. It was developed to define the principles of sustainable development and the possibility of its application in quantitative EIAs to determine the level and nature of the sustainable development of projects (Perdicoúlis and Glasson 2006; Lemons and Brown 2013). In the final step, the effective solutions to decrease the negative impacts on the environment were identified.

2. Overview of environmental pollutions at cement plants

Despite the economic benefits of the cement plants, environmental pollution by these plants is inevitable—these plants are one of the greatest environmental polluters. The pollution types include air pollution, noise pollution, groundwater pollution, loss of vegetation, etc. The following sections provide brief descriptions of these factors.

2.1. Air pollution

The cement industry plays an important role in the emission of many air pollutants. Enormous quantities of air pollutants are emitted from cement production units, including sulphur dioxide (SO_2), nitrogen oxides (NO_X), carbon monoxide (CO), carbon dioxide (CO_2), and particulate matter (PM). These result in significant regional and global environmental problems (Adak et al. 2007; Lei et al. 2011).

2.1.1. Dust

Without a doubt, the cement industry has been identified as an important source of dust. Dust is a subset of PM. Depending on the type of production, the particle diameter of dust in different intervals and at different times can be harmful for the health and environment. This is the most important factor to have a significant influence on the performance and health of people (Lei et al. 2011; Edalati M et al. 2014). Dust is emitted in the following activities in the cement production process: mining (drilling, blasting, loading, and haulage) in limestone, clay, Marley, gypsum, and iron mines; primary crushing, initial mixing and storage, grinding of raw materials, pre-heating, or using rotary kiln, silo (storage) clinker, cement mill, cement silos, or barn.

In the production of small particles such as dust particles, the formation of particles with diameters less than 10 microns is very important. These particles, known as PM10, are a major environmental factor. Due to its ability to escape and freely move about, PM10 is a major cause of lung and respiratory diseases. These diseases include aggravation of respiratory disorders and heart disease, lung tissue damage, premature death, lung cancer, silicosis, siderosis, and blepharoconiose (Mikulčić et al. 2013).

2.1.2. Gaseous air pollutants

Enormous quantities of air pollutants are emitted during cement production, including SO_2, NO_X, CO, and CO_2. The cement industry is one of the largest carbon-emitting industrial sectors in the world (Szabó et al. 2006). It contributes to about 5% of the world's anthropogenic CO_2 (Fidaros et al. 2007; Stefanović et al. 2010). Cement production releases large amounts of CO_2 from both fuel combustion and the chemical process for producing clinker, where calcium carbonate ($CaCO_3$) is calcined and reacted with silica-bearing minerals (Lei et al. 2011).

SO_2 mainly comes from the oxidation of sulphur in coal. In pre-calciner kilns, approximately 70% of SO_2 is absorbed by reaction with calcium oxide (CaO), while much less is absorbed in other rotary kilns and in shaft kilns (Su et al. 1998). Utilization of baghouse filters, as required in new pre-calciner kilns, can further reduce SO_2 emissions. It can be assumed that SO_2 absorption is 80% for the entire pre-calciner kiln process and 30% for other types of kilns (Lei et al. 2011).

Production of NO_X and CO is highly dependent on temperature and oxygen availability. Compared to shaft kilns, rotary kilns produce much more NO_X and less CO because of their higher operation temperature and stable ventilation (Lei et al. 2011).

The association of diseases such as persistent cough, mucus, and chronic bronchitis with SO_2 and NO_X emissions has been proved. The prevalence of these diseases in areas with severe pollution is two to three times more than that in less polluted areas (Lerman 1972).

2.1.3. Heavy metals

Raw materials and fuels used for cooking usually contain significant amounts of heavy metals such as mercury and cadmium. When the boiling temperature of heavy metals is less than the kiln temperature, the heavy metals in raw materials and fuels are released. In the cooking process, the heavy toxic metals are released into the environment and affect the surrounding ecosystem. The adverse effects on vegetation in areas surrounding cement plants are inevitable (Brown and Jones 1975).

2.2. Destruction of vegetation

Today, air pollution is a serious issue for the survival of plants in industrial areas. Development of industries is accompanied by increased influx of pollution on the environment and the surrounding ecosystem becomes more polluted. One of the worrisome results of the air pollution by cement plants is a considerable impact on the surrounding vegetation (Darley 1966; Kumar et al. 2008).

The cement industry plays an important role in the destruction of the ecological balance and abnormalities in environment. Pollution due to cement industry mainly includes dust emissions, heavy metals such as Mg, Pb, Cu, Cr, Hg, and Zn, and compounds such as fluoride, sulphate, and chloride. The above compounds enter the cycle of nature through the air, water, and soil, which are used as food by plants. Their concentrated presence in plants will lead to difficulties in the plants' metabolic activities (Migahid and Salama 1995; Mandre and Klõšeiko 1997).

According to the research, Portland cement kiln dust was found to be composed of finely ground cement raw materials ($CaCO_3$ and Na_2SO_4). It was observed that the cement deposit particles were quite alkaline. The effect of cement dust on the radiation balance and yield of plants was studied. The result of this research shows that the radiation intake of polluted plants increased, thus causing an increase in plant temperature and evapotranspiration. These results show a considerable damage to the plant species around the cement factories (Migahid and Salama 1995). Sometimes, these infected plants are consumed by animals and the harmful compounds enter their bodies and infect them (Lal and Ambasht 1982).

2.3. Noise pollution

Sound and vibrations in cement plants are produced by mining machinery, blasting, crushing, grinding, packaging machines, electro-motors, conveyor drive system, ventilators and blowers, kiln, etc. This type of pollution has a significant influence on the performance and health of employees, local residents, livestock, and wild animals of the region.

2.4. Water pollution

The contamination of water and soil resources by Chromium (Cr) compounds from the dust released into the environment through the chimneys of cement kilns and waste disposal has created serious environmental problems. These Cr (VI) compounds, both soluble and insoluble, are known to be human carcinogens. Chromium is a transition metal located in group VI-B of the periodic table. Although it can exist in several oxidation states, its most stable and common forms are the trivalent Cr (III) and the hexavalent Cr (VI) species, which display very different chemical properties. Cr (VI), considered to be the most toxic form of Cr, is usually associated with oxygen to form chromate (CrO_4^{2-}) or dichromate ($Cr_2O_7^{2-}$) ions. In contrast, Cr (III), in the form of oxides, hydroxides, or sulphates, is much less mobile and is mostly bound to organic matter in the soil and aquatic environments. Cr (VI) -a strong oxidizing agent- is reduced to Cr (III) in the presence of organic matter; this transformation is faster in acidic environments such as acidic soils. However, a high level of Cr (VI) may overcome the reducing capacity of the environment and thus persist as a pollutant. In addition, Cr (III) could also be transformed to the more toxic form of Cr (VI) in the presence of an excess amount of oxygen.

In recent years, with the increase in the number of cement plants and their capacities, the need of these plants to use Magnesia Chromite bricks for lining in baking kilns has increased. Cr (III), present on Magnesia Chromite bricks, changed to the more toxic form Cr (VI) due to heating on kilns and environment condition, is solution in precipitation and with precipitation, will be intrusion to the aquifer, and hence causes severe water pollution (Cervantes et al. 2001).

On the other hand, clinker stockpile creates drainage and leaching; these pollutants contaminate the surface and underground water. Therefore, the vegetation and animals of the region are affected. Consequently, human disease will be caused by the consumption of animal products.

Figure 1 shows the process of transfer of pollution from the chimney exhausts of cement kilns and waste disposal and the contamination of surface underground waters.

3. Positive effects of cement plants

Cement industries have considerable potentials, which have the greatest impact on the country's economic growth and this trend is growing. Other positive effects of cement industry include development of international relations, political, economic, social, and health development in the region, creation of jobs, improvement in public welfare and quality of life in the region, increase in regional and national income, attracting investment and future growth, reduction in migration in the region, and the creation of good access roads for the site and its residents.

4. Case study

The Shahrood cement plant is considered to be one of the most important and well-known industrial companies in the north-eastern part of Iran, due to its two production lines with 6,500 tonnes daily capacity of various types of grey Portland cement. The plant is located 12 Km from Shahrood City (North- Eastern Iran). The region's height above sea level, about 1,570 meters, is variable (Fig 2). This plant is surrounded by high-quality raw material (Fig 3). It is also equipped with the best laboratory equipment along with experienced experts, who can ensure high-quality products. This plant is placed close to urban areas as well as agricultural areas.

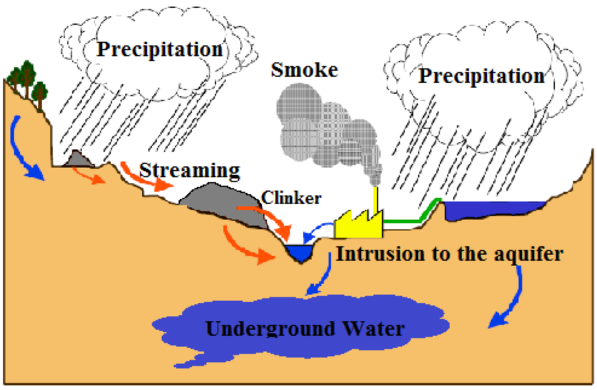

Fig 1. The process of transfer of pollution from the exhaust of the chimney of cement kilns and waste disposal and contamination of surface underground waters (after Charbonnier, 2001).

Fig 2. Shahrood cement plant.

5. EIA methods

The method considered here is based on the Folchi method, modified by Mirmohammadi et al. (2009). However, some slight modifications have been done to increase the number of influencing factors. Furthermore, a few changes have been made to use pre-influencing factors according to the case study being used. In this study, an EIA was conducted through the following steps (Mirmohammadi et al. 2007; Mirmohammadi et al. 2009; Monjezi et al. 2009):

1. Describing the environmental concepts in the fields of geology, geo-technology, hydrology, water, air, etc. Explaining environmental pollution and the positive effects of cement plants in Sections 2 and 3 of this study.
2. Determining the influencing factors and environmental components. The definitions and magnitudes of 18 overall factors introduced as impacting factors (IF) are listed in Table 1. Then the issues on which the influence of a mining activity is likely are defined as environmental components (EC) (Table 2). In this assessment method, it is necessary to introduce destructive and useful parameters at first. For the severely destructive parameters, the factor score is between zero and 10; zero means it is ineffective, while 10 shows the most critical condition. Some factors like the economic and cultural issues have a score between −10 and 10. The negative sign shows the positive effect.

Fig 3. Overview of Shahrood cement plant and limestone mine (Ataei and Sereshki 2016).

3. Defining the possible scenarios to cover the issues related to each IF, as a guide to evaluate the magnitude of each factor (in this section, tables are not given due to their extension; only the final scores of the IF are reported in Table 1).
4. Data collection: In the present study, the environmental data were collected based on the final opinion of the committee of mining environment, comprised of experts in this field.
5. Matrix formation: Environmental assessments are often performed using matrix methods, in which one dimension of the matrix is IF and the other one is the EC, which are affected by the IF. The next step in this algorithm was to designate the influence of IF on EC. The effect of each IF on each EC was expressed by the six statements - Nil (N), Very Low (VL), Low (L), Medium (M), High (H), and Very High (VH), and as numerical values of 0, 1, 2, 3, 4, and 5 respectively. Finally, a table was assembled, showing the effect levels of each factor on the components (Table 3).
6. Normalization: To obtain the normalized vector, the column vector elements were added together, and then each of the elements was divided by the whole. Due to the considered range for the levels of IF, the obtained values were multiplied by 10. The results are presented in Table 3.
7. EIA: Matrix C was obtained by multiplying Matrix F (the IF values) by Matrix M (the weighted value of each IF on each EC). The numbers in each column of Matrix C represent the effect on each EC.
Therefore, Eq. 1 is used to calculate the effect of IFs on each EC (Mirmohammadi et al. 2009):

$$[C]=[F][M] \quad (1)$$

where C represents a (1×13) matrix in which each element represents the amount of overall effect on each EC. Due to the nature of the method, this effect is shown as a fraction of 100 and is expressed in percentage. F denotes a (1×18) matrix in which elements represent the values of IFs and M is the quantitative matrix (18×13).
The results obtained are shown in Table 4. The components of Matrix C are depicted in a column graph (Fig 4), which describes the percentage of environmental damage for each EC separately.
From the results, it is clear that the amount of pollution for most of environmental components is considerable and the plant has a significant role in generating pollutants in the study area. Therefore, based on the obtained results, the control and reduction of these undesirable effects using necessary considerations is almost unavoidable. According to the results, the contamination produced by the plan for ECs like air quality, area landscape, soil of the area, ecology, and area usage is more significant that of other ECs. Hence, these results show that the Shahrood cement plant is somewhat harmful for the environment.

Table 1. Impacting factors (IF).

No.	Impacting factors (IF)	Magnitude	Score
1	Changing the usage of the area	0–10	6
2	Exposition of the area	0–10	10
3	Interference with surface water	0–10	6
4	Interference with underground water	0–10	2
5	Increase in the traffic of the area	0–10	10
6	Dust emission	0–10	10
7	Toxic pollutants and substance emissions to air	0–10	10
8	Noise pollution	0–10	7
9	Land vibration	0–10	5
10	Domestic employment	−10 to 10	−10
11	Population control	−10 to 10	2
12	Social and cultural development	−10 to 10	−8.5
13	Instability of the established spaces	0–10	2
14	Subsidence	0–10	2
15	Environmental arrangements	−10 to 10	−3
16	Light	0–10	1
17	Fly rock	0–10	8
18	Clinker dump	0–10	8

Table 2. Environmental components (EC).

No.	Environmental components (EC)
1	Human health and immunity
2	Social issues
3	Surface water
4	Underground water
5	Air quality
6	Area usage
7	Ecology
8	Surface constructions
9	Underground constructions
10	Area landscape
11	Quietness
12	Economic issues
13	Soil of the area

Table 3. Weighted values of effect of each impacting factor on each designed environmental component for cement plants.

Impacting factors	Environmental components												
	Human health and immunity	Social issues	Surface water	Underground water	Air quality	Area usage	Ecology	Surface constructions	Underground constructions	Area landscape	Quietness	Economic issues	Soil of the area
Changing the usage of the area	M	L	M	M	N	VH	L	N	N	VH	VH	H	VH
	0.484	0.488	1.2	1.364	0	1.667	0.833	0	0	1.563	1.667	0.755	1.563
Exposition of the area	N	VL	N	N	N	M	N	N	N	H	H	M	N
	0	0.244	0	0	0	1	0	0	0	1.25	1.333	0.566	0
Interference with surface water	M	N	H	H	N	M	H	N	N	H	N	VL	H
	0.484	0	1.6	1.818	0	1	1.667	0	0	1.25	0	0.189	1.25
Interference with underground water	M	N	H	VH	N	VL	H	N	N	N	N	VL	M
	0.484	0	1.6	2.273	0	0.333	1.667	0	0	0	0	0.189	0.938
Increase in the traffic of the area	H	H	N	N	H	VL	L	N	N	M	H	M	L
	0.645	0.976	0	0	1.739	0.333	0.833	0	0	0.938	1.333	0.566	0.625
Dust emission	VH	L	M	N	VH	L	L	N	N	H	N	M	VH
	0.806	0.488	1.2	0	2.174	0.667	0.833	0	0	1.25	0	0.566	1.563
Toxic pollutants and substance emissions to air	VH	M	L	VL	VH	L	L	N	N	N	N	VH	H
	0.806	0.732	0.8	0.455	2.174	0.667	0.833	0	0	0	0	0.943	1.25
Noise pollution	H	H	N	N	N	VL	L	N	N	N	VH	M	N
	0.645	0.976	0	0	0	0.333	0.833	0	0	0	1.667	0.566	0
Land vibration	VH	M	N	N	N	VH	M	VL	M	N	VH	M	N
	0.806	0.732	0	0	0	1.667	1.25	10	4.286	0	1.667	0.566	0
Domestic employment	N	VH	N	N	N	N	N	N	N	N	N	VH	N
	0	1.22	0	0	0	0	0	0	0	0	0	0.943	0
Population control	L	VH	N	N	N	M	N	N	N	N	L	VH	N
	0.323	1.22	0	0	0	1	0	0	0	0	0.667	0.943	0
Social and cultural development	M	VH	N	N	N	VL	N	N	N	N	N	M	N
	0.484	1.22	0	0	0	0.333	0	0	0	0	0	0.566	0
Instability of the established spaces	VH	N	N	N	N	N	N	N	N	N	N	VH	N
	0.806	0	0	0	0	0	0	0	0	0	0	0.943	0
Subsidence	N	N	N	N	N	N	N	N	H	N	N	N	N
	0	0	0	0	0	0	0	0	5.714	0	0	0	0
Environmental arrangements	VH	M	VH	VH	VH	VL	VL	N	N	VH	VH	VH	H
	0.806	0.732	2	2.273	2.174	0.333	0.417	0	0	1.563	1.667	0.943	1.25
Light	VH	N	N	N	N	N	N	N	N	N	N	L	N
	0.806	0	0	0	0	0	0	0	0	0	0	0.377	0
Fly rock	VH	H	N	N	N	N	L	N	N	L	N	L	N
	0.806	0.976	0	0	0	0	0.833	0	0	0.625	0	0.377	0
Clinker dump	VH	N	H	H	H	L	N	N	N	VH	N	N	VH
	0.806	0	1.6	1.818	1.739	0.667	0	0	0	1.563	0	0	1.563
Total	10	10	10	10	10	10	10	10	10	10	10	10	10

Table 4. Final scoring for each environmental component in Shahrood cement plant.

Impacting factors	Environmental components												
	Human health and immunity	Social issues	Surface water	Underground water	Air quality	Area usage	Ecology	Surface constructions	Underground constructions	Area landscape	Quietness	Economic issues	Soil of the area
Changing the usage of the area	2.903	2.927	7.2	8.182	0	10	5	0	0	9.375	10	4.528	9.375
Exposition of the area	0	2.439	0	0	0	10	0	0	0	12.5	13.333	5.66	0
Interference with surface water	2.903	0	9.6	10.909	0	6	10	0	0	7.5	0	1.132	7.5
Interference with underground water	0.968	0	3.2	4.545	0	0.667	3.333	0	0	0	0	0.377	1.875
Increase in the traffic of the area	6.452	9.756	0	0	17.391	3.333	8.333	0	0	9.375	13.333	5.66	6.25
Dust emission	8.065	4.878	12	0	21.739	6.667	8.333	0	0	12.5	0	5.66	15.625
Toxic pollutants and substance emissions to air	8.065	7.317	8	4.545	21.739	6.667	8.333	0	0	0	0	9.434	12.5
Noise pollution	4.516	6.829	0	0	0	2.333	5.833	0	0	0	11.667	3.962	0
Land vibration	4.032	3.659	0	0	0	8.333	6.25	50	21.429	0	8.333	2.83	0
Domestic employment	0	−12.195	0	0	0	0	0	0	0	0	0	−9.434	0
Population control	0.645	2.439	0	0	0	2	0	0	0	0	1.333	1.887	0
Social and cultural development	−4.113	−10.366	0	0	0	−2.833	0	0	0	0	0	−4.811	0
Instability of the established spaces	1.613	0	0	0	0	0	0	0	0	0	0	1.887	0
Subsidence	0	0	0	0	0	0	0	0	11.429	0	0	0	0
Environmental arrangements	−2.419	−2.195	−6	−6.818	−6.522	−1	−1.25	0	0	−4.688	−5	−2.83	−3.75
Light	0.806	0	0	0	0	0	0	0	0	0	0	0.377	0
Fly rock	6.452	7.805	0	0	0	0	6.667	0	0	5	0	3.019	0
Clinker dump	6.452	0	12.8	14.545	13.913	5.333	0	0	0	12.5	0	0	12.5
Total	47.339	23.293	46.8	35.909	68.261	57.5	60.833	50	32.857	64.063	53	29.34	61.875

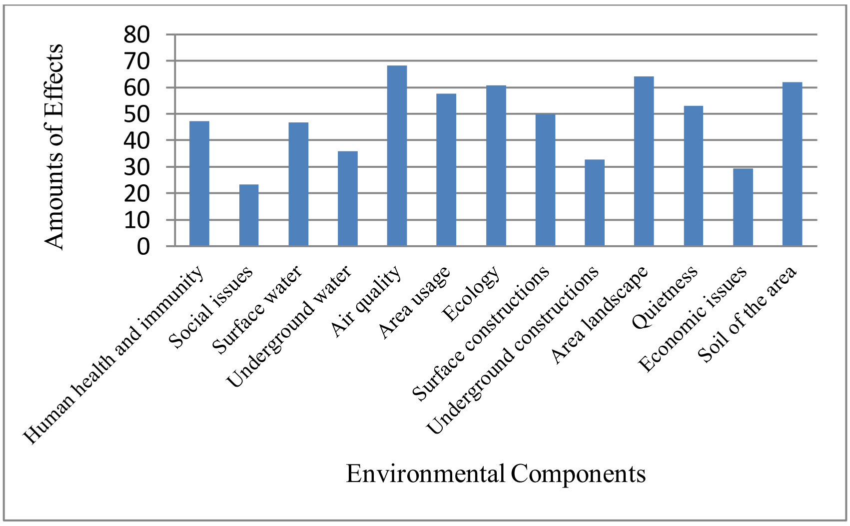

Fig 4. Amount of overall effect of impacting factors on each environmental component for the Shahrood cement plant.

6. Mathematical Model of Sustainability

As mentioned earlier, the mathematical model of sustainability for the definition of sustainability, parameters, constraints of the key components, and the conditions in which sustainability or unsustainability can occur have been developed by (Phillips 2012b; Phillips 2012c; Phillips 2012a). The steps to use this model are as follows:

1) Perform EIA

In this study, the results indicated in the final row of Table 4 (Fig 4) form the basis for the application of the model in the calculation of an indicated level and the nature of sustainable development for the operation of cement plants.

2) Application of model by stating all the project options and determining the environmental and human components.

- Determining all project options for evaluation, e.g. project over time (before–during–after) or project alternatives in the design or operation phase
- Determining the EC (depicted as E in the equation) to be used in the calculations.

All the studied ECs along with the corresponding symbols are shown in Table 5.

- Determining the human components (H_{NI}) to be used in the calculations. Table 6 shows the environmental components and relevant symbols.
- Determining the maximum scores of environmental and human components.

In this method, the maximum score is 100 for environmental and human components. The respective total scores for the EC and H_{NI} are presented in Table 7.

Table 5. Environmental components.

Air quality	A_1
Quietness	A_2
Ecology	B_1
Surface water	H_1
Underground water	H_2
Area usage	L_1
Surface constructions	L_2
Underground constructions	L_3
Area landscape	L_4
Soil of the area	L_5

Table 6. Human components.

Human health and immunity	H_{NI1}
Social issues	H_{NI2}
Economic issues	H_{NI3}

Table 7. Maximum Scores of E and H_{NI} components.

E and H_{NI} Components	Value
A_{max}	200
B_{max}	100
H_{max}	200
L_{max}	500
E_{max}	1,000
$H_{NI\,max}$	300

3) Calculating E for the project options from Eq. 2.

$$E=\frac{[(\sum A_{max}-\sum A)+(\sum B_{max}-\sum B)+(\sum H_{max}-\sum H)+(\sum L_{max}-\sum L)}{(\sum A_{max}+\sum B_{max}+\sum H_{max}+\sum L_{max})}$$

Or

$$E=\frac{[(\sum A_{max}-(A_1+A_2))+(\sum B_{max}-B_1)+(\sum H_{max}-(H_1+H_2))+(\sum L_{max}-(L_1+L_2+L_3+L_4+L_5))}{(\sum A_{max}+\sum B_{max}+\sum H_{max}+\sum L_{max})} \tag{2}$$

$$E=\frac{[(200-(68.261+53))+(100-60.833)+(200-(46.8+35.909))+(500-(57.5+50+32.857+64.063+61.875))}{(200+100+200+500)}=0.468902$$

4) Calculating H_{NI} for the project options from Eq. 3.

$$H_{NI}=\frac{[(H_{NI1}+H_{NI2})+(H_{NI3max}-H_{NI3})]}{\sum H_{NI\,max}} \tag{3}$$

$$H_{NI}=\frac{(47.339+23.293)+(100-29.34)}{300}=0.470973$$

5) Determining whether the project option is sustainable.

- Listing the values obtained for E and H_{NI}.
- If the value obtained for E is greater than that for H_{NI}, then it is sustainable:

$E > H_{NI} \leftrightarrow S > 0$

- If the value obtained for E is less than/equal to that for H_{NI}, then it is unsustainable:

$E \le H_{NI} \leftrightarrow S \le 0$

$E = 0.468902 \le H_{NI} = 0.470973$

$E = 0.468902 \le H_{NI} = 0.470973 \leftrightarrow S \le 0$

As the calculated value for E is less than that for H_{NI}, the project under evaluation is unsustainable.

6) If project is sustainable, calculating the S value for the project option, and determining the level and nature of sustainability using the ranges defined in Table 8.

$S = E + H_{NI}$

Table 8. S value and level ranges.

Range	Sustainability
0.751–1.000	Very Strong
0.501–0.750	Strong
0.251–0.500	Weak
0.001–0.250	Very Weak

According to the results obtained in the previous stage (Stage 5), this complex is unsustainable. Therefore, the preventive environmental activities must be recommended with a preference to reduce the environmental damages to its components. These recommended solutions are given in the next section (Section 7).

7. Preventive activities to reduce the environmental damages due to cement plants

Some preventive activities that can be done are:

- Using dust-collection systems and recovering dust caused by grinding of raw materials
- Timely maintenance of all systems
- Monitoring of air quality parameters in daily and continuous period times
- Use of clean fuels, including minimum NO_x and SO_x, and optimizing fuel consumption
- Planning for Pozzolan cement production in order to reduce CO_2 emissions by about 20–30%
- Development of green spaces in and around the plant and a steady increase in tree-planting
- Use of energy from kiln exhaust gases to produce steam and electrical energy
- By enlisting the modern facilities of preheater, pre-calcined and cooling, the efficiency of cement kilns significantly increases and power consumption per Kg of cement is reduced to less than half.
- To eliminate noise pollution at cement plants, soundproof insulation materials and individual equipment must be used.
- Location of clinker depot should be indoors and it should be covered.
- Using bricks made of aluminium and magnesium compounds instead of chromite bricks for cement kiln insulation.

8. Conclusions

Nowadays, in order to achieve sustainable development, major attention is being focused on industries in the context of the preservation of the environment and improvement of people's lives, in order to reduce serious risks for future generations. So, EIA for industrial and mining activities is necessary for preventing and controlling environmental problems. Focusing on EIA as a new tool to determine the harmful effects of the projects on the environment is very necessary. Therefore, understanding the effects of activities in potentially polluting centres will be a great help for determining the future strategies. Assessment of the environmental impact of mines and plants, like other industrial projects, is very important in order to control environmental problems. Environmental assessment is a multidimensional tool that depends on the domestic and local characteristics of each case study. Hence, these kinds of overall assessment should be considered as the first step and just a total evaluation. The environment is a key element of sustainable development in each country. The lack of attention to the environment issue and natural resources is the reason of human damage, due to which this problem has worrisome implications. Iran is one of the largest cement producers in world, and cement industries are one of the largest energy-intensive and polluting industries. Hence, the environmental subject and ecological effects of this product become a very important topic.

The Shahrood cement plant has significant environmental and human impacts on the area. In this study, a new model has been presented for the quantitative EIA using the matrix method.

A more precise evaluation for each case study needs some modification and has the ability to be easily modified because of its simple and understandable nature. Among the environmental assessment methods, the matrix method, i.e. the modified Folchi method, is a valuable technique due to its capability for quick estimation. In this study, almost all of the factors impacting environmental components were considered. The results obtained in this study can help prioritize the environmental activities to reduce the negative effects of cement plants. The importance of prioritizing lies in the time and financial constraints in the simultaneous response and reaction to all the environmental damages.

According to the results, the contamination produced by the plant in environmental components like air quality, area landscape, soil of the area, ecology, and area usage is more significant than that in other environmental components. Hence, it is recommended that these components be given priority in order to allocate the resources and take preventive measures. Finally, the results of the environmental assessment were studied for evaluating the sustainability of the project using the Phillips mathematical model. The Phillips model indicates the potential value of the application of the model to an EIA in determining and resolving questions of sustainability/unsustainability. The approach described by the Phillips model could offer further potential for the evaluation of a project before, during, and after construction. This complex is unsustainable; therefore, the preventive environmental activities must be recommended with a preference in order to reduce the damages to environmental components.

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