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Application of multi-attribute decision-making methods in SWOT analysis of mine waste management (case study: Sirjan's Golgohar iron mine, Iran)

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ABSTRACT

Mines provide essential materials for life and human progress; however, on the other hand, the possibility of life and having healthy environment is adversely affected by increasing pollution. Mine waste (tailing) is one of the pollutants generated by mines that should be properly managed. Nowadays, strategic management by using appropriate tools and technology is essential for the proper management of waste everywhere, including the urban, rural, medical, industrial, and mining environments. This study aims to identify strengths, weaknesses, opportunities, and threats (SWOT), and strategies for waste management in iron mines and provide a quantitative basis to analytically determine the ranking of the factors in SWOT analysis via conventional multi-criteria decision-making methods: Analytical Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS).

The AHP method was used to calculate the weights of evaluation criteria and the TOPSIS method was preferred because of its capability to use both negative and positive criteria among the SWOT factors. The results of the evaluation matrix of internal and external factors showed that overall, the strengths overcame the weaknesses. However, if the opportunities are used well and correctly, threats can be overcome and weaknesses can be eliminated. Therefore, strategies based on weaknesses–opportunities (WO) are first priority. Sixteen strategies that are presented based on the SWOTs and prioritized based on TOPSIS could be useful for Sirjan's Golgohar iron ore to develop and promote its future mine waste management at the strategic level.

1. Introduction

With the development of mining industry, mining exploitation activities have produced more and more solid wastes and induced increasingly grievous destruction on eco-environment. Waste rock, tailings and other solid waste are the largest industrial solid waste generated in the process of exploitation of mineral resources (Zengxiang and MeifengCai, 2012). Mining wastes include waste generated during the extraction, beneficiation, and processing of minerals. Most extraction and beneficiation wastes from hard rock mining (the mining of metallic ores and phosphate rock) (Mining Waste, 2015). In other words, waste generated through mining in the form of overburden and coal processing in the form of rejects and tailings has been defined as mineral waste (BHP, 2009). In general, mine tailings are mechanically, physically, chemically and biologically deficient (Vega et al., 2004), characterized by instability and limited cohesion, with low contents of nutrients and organic matter and high levels of heavy metals (He et al., 2005). Opencast mining activities have a serious environmental impact on soils and water streams, generating millions of tons of mine tailings (Bhattacharya et al., 2006).

Incidents of poor waste management practice are amongst the most conspicuous features of the global minerals industry. Tailings spills, dam failures, seepage, un-rehabilitated sites and cases of direct discharge into water ways can result in severe and long-term environmental and social consequences (Van Zyl, 1993; ICME and UNEP, 1998; Hart, 2007; Franks, 2007; Spitz and Trudinger, 2009; Fourie, 2009).

Mine and mineral processing wastes have the potential to leave

Abbreviations: AHP, Analytical Hierarchy Process; FAHP, Fuzzy Analytical Hierarchy Process; ANP, Analytic Network Process; EPA, Environmental Protection Agency; HSWA, Hazardous and Solid Waste Amendments; MCDM, Multi-criteria decision making; NIS, Negative ideal solution; PIS, Positive ideal solution; RCRA, Resource Conservation and Recovery Act; SO Strategy, Strategy based on strengths-opportunities; ST Strategy, Strategy based on strengths-threats; SWDA, Solid Waste Disposal Act; SWOT, Strengths, Weaknesses, Opportunities and Threats; TOPSIS, Technique for Order Preference by Similarity to Ideal Solution; FTOPSIS, Fuzzy Technique for Order Preference by Similarity to Ideal Solution; WO Strategy, Strategy based on weaknesses- opportunities; WT Strategy, Strategy based on weaknesses-threats

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environmental, social and economic legacies for thousands of years (Kempton et al., 2010), as evidenced by sites such as the Rio Tinto estuary in Spain, where surface water contamination is still present from historic mining as early as 4500 years ago (Leblanc et al., 2000). Therefore, because of the high volume of mining waste and it being hazardous for the environment, mining waste management is very important, which must be carefully and seriously considered.

In this among the Environmental Protection Agency (EPA) implements the Solid Waste Disposal Act of 1978 (SWDA), as amended by Resource Conservation and Recovery Act (RCRA), as amended by the Hazardous and Solid Waste Amendments (HSWA) of 1984 (collectively referred to as RCRA) to protect human health and the environment from problems associated with solid and hazardous wastes.

Mining wastes are included in RCRA's definition of solid waste, and in 1978, when EPA proposed regulations for the Subtitle C hazardous waste program, special management standards were proposed for mining wastes. However, in 1980, RCRA was amended to include what is known as the Bevill Amendment (RCRA §3001(b)(3)(A)). The Bevill Amendment provides a conditional exclusion from RCRA Subtitle C hazardous waste requirements for wastes from the extraction, beneficiation, and processing of ores and minerals. The exemption was conditioned upon EPA's preparation of a report to Congress on the wastes and a subsequent regulatory determination that regulation under Subtitle C was appropriate (EPA, 1994).

Many studies have been performed on mining waste management in various countries. For instance Zengxiang and MeifengCai (2012) performed a study on mining waste with the aim to study comprehensive utilization of mining waste. They mentioned that choosing the right varieties for the comprehensive utilization of mining waste and controlling contamination from waste rocks and tailings are very important issues for the disposal of mining waste; moreover, environment-friendly disposal of solid wastes from mines is the key (Zengxiang and MeifengCai, 2012). Franks et al. (2011) developed a set of sustainable development principles for the disposal of mining and mineral processing wastes, and discussed the implications for current and future practice (Franks et al., 2011).

Nikolaouand Evangelinos (2010) conducted research on the Greek mining industry. They focused on the challenges faced by mines when applying the environmental principles to mines and mineral industries and restoring operational sites that were environmentally valuable. According to their study, the Greek mining industry has responded to these challenges by introducing environmental management practices or holistic environmental management systems to mainly restore environmentally depreciated operation sites by eliminating the use of environmental resources, managing waste production, eliminating water use, and controlling other environmental impacts. They utilized SWOT analysis to examine the strengths, weaknesses, opportunities, and threats (Nikolaou and Evangelinos, 2010).

Ostrega et al. (2011) conducted research to understand how to minimize environmental impacts due mining activities. They studied challenges such as water discharge, dewatering, smelting, dust pollution, transportation, and mineral depletion that require careful planning, tactical investment, and strategic management. ANP and SWOT approach were used and four alternative strategies were created as follows: mineral extraction, mineral processing, water discharge, and waste handling in this study through the ANP–SWOT Model (Ostrega et al., 2011).

In this study, a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis was performed to analyze the situation of mining waste management and to prepare strategic factors for waste management, in order to weighting and prioritizing that factors the FAHP (Fuzzy analytic hierarchy process) was used. Moreover, the FTOPSIS (Fuzzy technique for order preference by similarity to the ideal solution) approach was applied to prioritize the strategic alternative for mining waste management. TOPSIS and AHP are multi-criteria decision making (MCDM) methods. The merit of MCDM methods is their ability to solve complex and multi criteria problems by handling both quantitative and qualitative criteria. The MCDM methods are strong tools for determining the best alternative among a pool of the feasible alternatives.

2. Materials and methods

2.1. Case study

The case study area of this research is Golgohar mining and industrial complex (29°7′5″N and 55°19′5″E) which is located in 55 km of South West of Sirjan city in Kerman province, south of Iran. According to Iran's National Census in 2006, the population of Sirjan is 167,014, scattered in 40,605 families and Golgohar complex is the main source of revenue for the city.

The case study area is located at an altitude of 1730 m above the sea level; it is situated in a depression between the southern Zagros Mountains to the west and the Kuh-e-Bidkhan massif to the east (Sirjancounty, 2015). Based on the De martonne method, the drought index is 39/6 and based on this classification, the case study area's climate is dry (KoushaMadan, 2012) [Unpublished observations]**.** It is worth noting that Golgohar mining and industrial complex meets 30% of steel factory needs in Iran.

There are four plants in Sirjan's Golgohar complex and three of them perform ore beneficiation and concentration processes. These three plants include the magnetite processing plant, hematite recovery and desulfurization plant, and Polycom processing plant. The fourth is a pelletizing plant that is responsible for the agglomeration of the concentrates produced by the three plants. Each plant produces various wastes according to their processes and the row and additive materials used by them.

According to the information obtained after waste assessment in the Golgohar mining region, interviews with managers and experts, and review of the reports and technical documents, the waste produced in the mining region includes tailing rock and soilresulting from the extraction; dry and wet tailing resulting from magnetic separation; and effluent resulting from the flotation cells containing tailings and reagents used in flotation.

2.2. Data gathering

Data supporting the analysis were derived from multiple channels and collected in two separate groups including:

– *The first group* was qualitative information related to internal and external factors affecting aspects of waste management in Golgohar Complex. In fact, the strategic factors that have been identified in several ways.

1. Study of plant documentation and the annual environmental reports related to the company
2. Inspections of the production processes of the company and types of waste produced
3. Inspections of waste disposal sites and tailings dam.
4. The case sampling of waste produced in different sectors and laboratory analysis in order to evaluate the hazardous waste elements.
5. Finally, using techniques of interview, brainstorm and distribution of questionnaire among experts and gathering their views and the final listing the internal and external strategic factors and extraction of important strategies based on these factors.

On the whole to overcome some of the challenges, information was obtained from annual environmental reports of the environment unit and technical documents of plants in which real and more accurate data, such as MSDS instructions and executive program's reports of