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Qualitative and Quantatitve Investigation of Industrial Solid Waste in the Iron Ore Extraction and Processing Sectors of Golgohar Mining and Industrial Company

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A R T I C L E I N F O

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ABSTRACT

Introduction: In order to achieve sustainable development in mining, waste management is an essential requirement. The current study aimed to examine industrial solid waste produced in Golgohar Mining and Industrial Company, which is a well-known iron ore extraction and processing complex.

Materials and Methods: This cross-sectional study was conducted in two phases from March, 2016 through March, 2017. In the first phase, the data related to the production process and quantity/quality of produced wastes were collected through conducting field observations, interviewing production, environmental experts in Golgohar Mining and Industrial Company, and examining the gleaned evidence. In the second phase, the XRF was used to examine the composition of processing tailings following the ISO 9516-1: 2003.

Results: In total, 16, 19, and 17 types of industrial wastes were respectively identified in the extraction sector, the magnetite processing plant, and the polycom processing plant of Golgohar Mining and Industrial Company and 12, 14, and 12 types of which (in the same order) were recyclable. The ingredients of iron ore processing tailings encompassed quartz, manganese oxide, iron oxides, aluminum oxide, calcium carbonate, sulfur, potassium oxide, sodium oxide, titanium oxide, phosphorus, chromium oxide, and barium oxide. The largest proportion (32.9%) was recorded for quartz in dry tailings.

Conclusion: It is essential to pay more attention to recycling in such industries. Improving production processes for retrieve more iron and the use of mineral wastes as raw materials for other industries can reduce the problems associated with such wastes (eg low storage space and environmental problems).

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Introduction

As a result of industrial development in recent years, the economy of Iran is becomiang more dependent on industry (as a replacement for agriculture) [1]. The development of mineral industries had led to a rapid growth in mining activities, which in turn have resulted in the production of large volumes of waste jeopardizing the environment [2]. The concept of industrial waste entails every type of waste which is produced as a result of industrial activities or is derived from industrial processes. In other words, industrial waste includes every material other than the main product that is yielded as a result of industrial processes. If these extra materials are not fluid and are not shaped like their passage way, they are known as solid waste. The fluid materials, on the other hand, are called industrial wastewater or materials released in the air [3, 4]. Industrial wastewater is produced as a result of industrial and mining activities. They may also be yielded through refinery processes in gas, oil, petrochemical, and power plant industries [5]. In contrast, mining waste encompasses solid and liquid wastes produced as a result of extraction and processing of ore in mines or nearby areas [6]. In other words, the waste that is produced through mining activities is known as mining waste and includes the returned load or trash. Iron ore waste is produced in iron ore industries and entails very tiny particles remained as a result of extracting iron from iron ore. The problems of disposing iron ore waste include lack of enough space, technical difficulties, costs, and environmental risks [7]. According to incomprehensive estimates, a total of 2×10^9 tons of iron ore waste was produced in 2009 [8]. Thus, responsible management of wastes is commensurate with the sustainable development of mining [9]. The first step in waste management is studying the amount, type, and the composition of produced wastes [9, 10]. Various studies have been conducted with regard to the wastes of different industries [1, 10-15]. Given that no published study has focused on solid waste produced in iron ore extraction and processing in Iran, the current study aimed to examine industrial solid waste produced in Golgohar Mining and Industrial Company from March, 2016 through March, 2017, which is a well-known mining complex.

Study area

The study area included Golgohar Mining and Industrial Company, which is 50 km from Sirjan, Kerman, in the southwest (29°7′5″N & 55°19′5″E). Golgohar iron ore is located in six different anomalies encompassing a 10 × 4 km area. The mineral mass which is being extracted at the present time is Zone 1 with a reservoir of 145 million tons. Two processing plants with 4 production lines have been established in Zone 1 to process the extracted iron ore. These factors can produce 8 million tons of iron concentrate each year using both wet and dry modes (Figure 1).

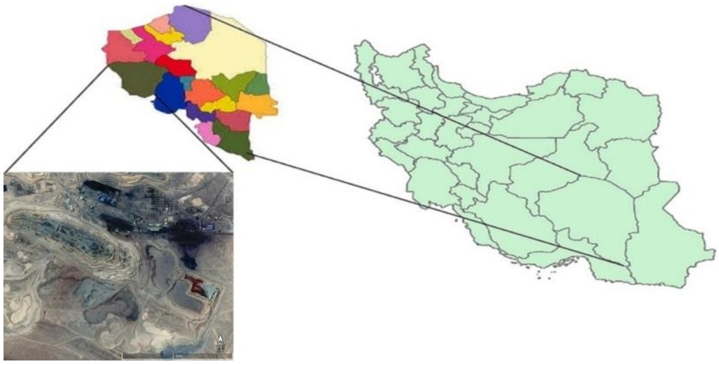

Figure 1: Study area

Materials and Methods

The study was conducted in two phases from March, 2016 through March, 2017. In the first phase, the data related to the production process as well as quantity/quality of produced wastes were collected through conducting field observations, interviewing production and environmental experts in Golgohar Mining and Industrial Company, examining the evidence related to waste management, studying chemical analyses and material safety data sheets

(MSDS), and examining the completed self-declaration form of the operational program for executive management of industrial and specific wastes, which is submitted to the Department of Environment [16]. In the second phase, in line with ISO 9516-1:2003, X-ray fluorescence (XRF) was used to examine the produced wastes as a result of iron ore processing. Loss on ignition (LOI) was also estimated following ASTM D2974 [17]. Hence, 8 wet and dry tailing samples produced after processing iron ore were collected and transferred to the laboratory of Golgohar Mining and Industrial Company for further analysis.

Ethical issues

Ethical approval was obtained from the Ethics Committee of Shahid Sadoughi University of Medical sciences, Yazd, Iran (ID: IR.SSU.SPH.REC.1395.54).

Results

Table 1 illustrates the amount and source of industrial wastes produced in Golgohar Mining and Industrial Company. The table also contains information on whether these wastes are recyclable or not. Accordingly, 16 different types of industrial wastes are produced in the iron ore sector of Golgohar Mining and Industrial Company, with the highest amount of rock and soil wastes produced after extracting iron ore from the mine. In total, 4 types of wastes are not capable of being recycled, while the rest are recyclable.

Table 1: List of major identified industrial waste and their source in the extraction section of the Golgohar Mining and Industrial Company.

Order index	Waste	Waste Generation (Kg/year)	Waste source	Recyclability
1	Scrap Tires	80500	Machinery	Recyclable
2	Used oils	105000*	Machinery	Recyclable
3	Oil filters	7000	Machinery	Recyclable
4	Gas oil filters	4700	Machinery	Recyclable
5	Air filters	3000	Machinery	Recyclable
6	Steel Waste	83440	Machinery	Recyclable
7	Other metal waste	100130	Machinery	Recyclable
8	Oil drums	5060	Oil tanks	Recyclable
9	Cleaning textile	600	Machine workshop	Non-recyclable
10	Lead and acid batteries	800	Machinery	Recyclable
11	Emulite	200	Explosive materials	Recyclable
12	Cable and wire	4000	Machinery	Recyclable
13	Brake pads	140	Machinery	Recyclable
14	Wireless battery	2	Operation unit	Non-recyclable
15	Fluorescent tube	25	Buildings and offices	Non-recyclable
16	Tailings rock and soil	27936590**	Mine	Non-recyclable

*(Liter/year), **(Ton/year)

Table 2 reveals that there are 19 types of industrial wastes which are produced in the magnetite iron ore processing plant of Golgohar Mining and Industrial Company using dry process. In total, 5 types of wastes are not recyclable, whereas the other 14 types can be recycled. The largest bulk of identified dry wastes are produced as a result of processing iron ore. They are currently not recyclable and are being deposited in an area close to the mine.

Table 2: List of major identified industrial wastes and their source in the magnetite iron ore processing plant of the Golgohar Mining and Industrial Company

Order index	Type of waste	Waste Generation (Kg/year)	Waste source	Recyclability
1	Used oils	45000*	Ball mill	Recyclable
2	Burned grease	600	Ball mill	Non-recyclable
3	Wire Conveyor	44000	Material transfer	Recyclable
4	Conveyor belt	26000	Material transfer	Recyclable
5	Cleaning textile	540	Repair and lubrication unit	Non-recyclable
6	Swarf	2000	Turning	Recyclable
7	Rubber liners	32000	Ball mill	Recyclable
8	Steel liners	500000	Ball mill, Output shot	Recyclable
9	Abrasion parts of pumps	3200	Transfer water and tailing	Recyclable
10	Cloth Disk filter	3000	Disk filter	Non-recyclable
11	Polyethylene pipe	12000	Material transfer	Recyclable
12	Imket bars	1300	Ball mill	Recyclable
13	Sector Rubber	2500	Disk filter	Non-recyclable
14	Lifter bars	10000	Ball mill	Recyclable
15	Shell plat	1750	Ball mill	Recyclable
16	Rubber underneath liners	800	Input Ball mill	Recyclable
17	U shape Rubber	600	Ball mill	Recyclable
18	Steel Waste	90000	Production Process	Recyclable
19	Dry tailings	5282108**	Iron ore processing	Non-recyclable

*(Liter/year), **(Ton/year)

In the polycom iron ore processing plant of the Golgohar Mining and Industrial Company, 17 types of industrial wastes are produced using the wet process. Table 3 displays the amount of waste produced annually, the place of production, and recyclability of the wastes. The largest volume of wet tailings is produced as a result of processing iron ore. In general, 12 types of identified wastes are recyclable, while 5 types cannot be recycled.

Table 3: List of major identified industrial waste and their source in the Polycom iron ore processing plant of the Golgohar Mining and Industrial Company

Order index	Type of waste	Waste Generation (Kg/year)	Waste source	Recyclability
1	Used oils	30000*	HPGR, Ball mill	Recyclable
2	Rubber liners	35000	Ball mill	Recyclable
3	Abrasion parts of pumps	1800	Pumps	Recyclable
4	Cloth of Belt Filter	3000	Belt filter	Non-recyclable
5	Friction tapes of Belt Filter	2800	Belt filter	Non-recyclable
6	Cloth bag filter	1200	Bag filter	Non-recyclable
7	Conveyor belt	48000	Material transfer	Recyclable
8	Polyethylene pipe	5000	Transfer water and tailing	Recyclable
9	Steel Waste	70000	Production Process	Recyclable
10	Pallet	1200	Packaging Equipment	Recyclable
11	Metal Rollic	2500	Material transfer	Recyclable
12	Rubber Rollic	1800	Material transfer	Recyclable
13	Rubber belt	4300	Material transfer	Recyclable
14	Liners	780	Ball mill	Recyclable
15	Cleaning textile	340	Repair and lubrication unit	Non-recyclable
16	Paper	1200	Packaging	Recyclable
17	Wet tailings	1845790**	Iron ore processing	Non-recyclable

*(Liter/year), **(Ton/year)

As shown in Figure 2, the percentage of recyclable industrial wastes except mineral wastes produced in the extraction section, magnetite and polycam plant of the Golgohar Mining and Industrial Company is respectively 99.8%, 99% and 96%. The percentage of mineral wastes in the extraction section, polycom and magnetite plant is respectively constitute 80%, 15%, and 5% of mining tailings produced in Golgohar Mining and Industrial Company (Figure 3).

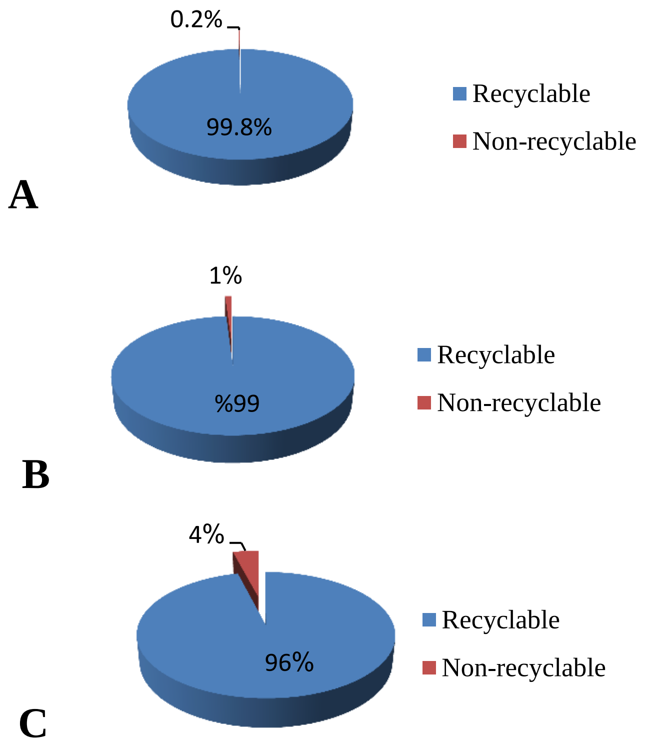

Figure 2: The percentage of recyclable and non-recyclable industrial wastes except mineral wastes A) extraction section B) magnetite plant C) Polycom plant

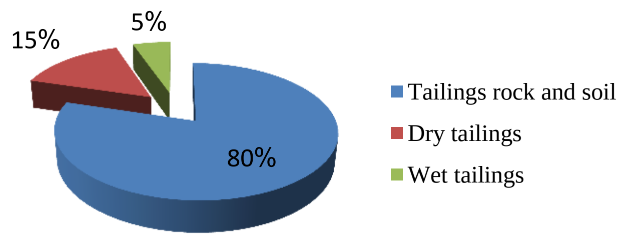

Figure 3: The percentage of mineral wastes produced in Golgohar Mining and Industrial Company

Composition of mineral wastes

The results of the XRF analysis are demonstrated in Table 4. It is observed that the major wastes produced as a result of processing iron ore in Golgohar Mining and Industrial Company include quartz, manganese oxide, iron oxides, aluminum oxide, calcium carbonate, sulfur, potassium oxide, sodium oxide, titanium oxide, phosphorus, chromium oxide, and barium oxide. Table 4 also depicts LOI values and the proportion of dry and wet tailing compositions (in percentages). The mean percentage of composition Dry and wet tailings shown in Figure 4.

Table 4: Percentage composition of wet and dry tailings of processing iron ore in Golgohar Mining and Industrial Company

	Tailing									
	Dry				Mean ± SD	Wet				Mean ± SD
	1	2	3	4		1	2	3	4	
SiO_2	32.68	32.06	32.13	34.78	1.3 ± 32.9	30.81	28.54	29.8	30.13	29.8 ± 0.95
Al_2O_3	8.02	7.38	7.48	8.12	7.8 ± 0.37	5.17	6.42	6.22	4.9	5.7 ± 0.75
BaO	0.01	0.01	0.02	0.01	0.013 ± 0.005	0.01	0.01	0.01	0.01	0.01 ± 0
CaO	6.47	6.7	6.11	6.45	6.4 ± 0.24	6.7	8.26	7.65	7.36	7.5 ± 0.65
Fet	13.7	12.8	13.3	11.9	12.9 ± 0.78	13.8	14.1	13.2	11.4	13.1 ± 1.2
K_2O	0.84	0.94	0.96	1.21	0.98 ± 0.58	0.78	0.53	0.82	0.79	0.7 ± 0.13
MgO	18.77	12.82	11.86	12.06	13.9 ± 3.3	14.56	19.86	15.65	15.55	16.4 ± 2.4
MnO	0.05	0.42	0.059	0.067	0.15 ± 0.19	0.063	0.037	0.043	0.06	0.05 ± 0.01
Na_2O	0.76	0.82	0.98	0.46	0.76 ± 0.22	0.96	0.73	0.89	0.7	0.82 ± 0.13
P	0.35	0.39	0.36	0.28	0.35 ± 0.047	0.47	0.64	0.527	0.46	0.52 ± 0.08
S	4.32	5.1	4.2	3.85	4.37 ± 0.53	4.6	3.7	4.8	3.3	4.1 ± 0.7
TiO_2	0.62	0.48	0.47	0.56	0.52 ± 0.07	0.42	0.26	0.31	0.39	0.34 ± 0.07
Cr_2O_3	0.01	0.01	0.01	0.01	0.01 ± 0	0.01	0.01	0.01	0.01	0.01 ± 0
LOI	11.51	11.86	10.8	9.12	10.8 ± 1.2	11.3	12.1	11.12	10.6	11.3 ± 0.62

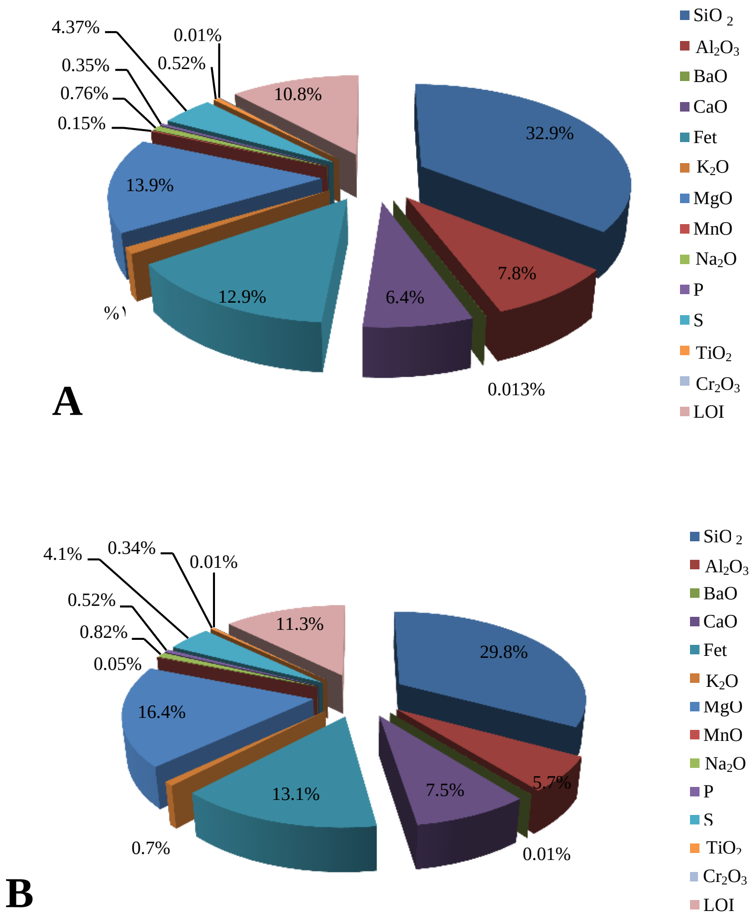

Figure 4: The mean percentage of composition: A) Dry tailings B) Wet tailings

Discussion

According to Table 1, mineral machinery constitutes the major source of producing industrial wastes in the extraction sector. The largest proportion of industrial waste (save for soil tailings and rock produced as a result of iron ore extraction) in the extraction sector of Golgohar Mining and Industrial Company belongs to burnt oils. The same results were obtained by Ahmadi et al., who investigated the wastes produced in a petrochemical complex in the west of Iran [18]. Burnt oils produced in Golgohar Mining and Industrial Company are now collected and transferred to refiners. As illustrated in Figure 2, 99.8% of solid wastes (save for soil tailings and rock produced as a result of iron ore extraction) produced in the extraction sector are recyclable. Nevertheless, the main problem in this sector is related to worn tires. Although they are recyclable, they are deposited in a nearby location and do not undergo any recycling due to their large volume (they belong to mining machinery) and high transportation costs. Indeed, worn tires constitute 29% of industrial wastes produced in the extraction sector. Given that several other mines are located in Golgohar, it seems that constructing a factory for recycling worn tires is economically justified and can significantly reduce environmental problems related to depositing such wastes. Oraee et al. compared the efficiency of using trucks and conveyor in Gohar Zamin Iron Ore Company. They reported that utilizing conveyor and crusher cavity for transporting the extracted iron ore is economically and technically more justifiable than using trucks. Since the major proportion of produced wastes in the extraction sector has to do with mining machinery, it seems that using conveyor and crushing cavity can considerably reduce the amount of produced industrial waste [19]. Tables 2 and 3 display the identified solid wastes produced in the iron ore processing sector of Golgohar Mining and Industrial Company. It is observed that 19 types of wastes were identified in the magnetite plant, and 5 of which were recyclable. On the other hand, 17 types of wastes were registered in the polycom plant, 5 of which have the capacity of recycling. Therefore, the total proportion of recyclable wastes in the magnetite and polycom plants are 99% and 96%, respectively. Studying the wastes produced in Semnan Industrial Park, Ayati et al. identified 32 types of wastes. They argued that 4 types of these wastes were large enough to be recycled. Discrepancies in the type of wastes can be attributed to the presence of various industries in different industrial parks [20]. As a considerable proportion of industrial wastes in Golgohar Mining and Industrial Company, mining tailings are of three types: soil, the rock produced as a result of extracting iron ore, dry/wet tailings produced as a result of processing iron ore. These three types of tailings respectively constitute 80%, 15%, and 5% of mining tailings (Figure 3). Mining tailings, which mainly include the soil dug for accessing the iron ore reservoir, amounted to 27936590 tons at the time of data collection (Table 1). These tailings are now being deposited in a nearby area. These tailings may be used in future to reconstruct the mining site [21]. Lu and Cai elicited waste producers' ideas on the best procedures to dump mining wastes with the aim of reusing them in a comprehensive way. They came up with new ideas. For example, they suggested that the sand that is produced in ore processing can be retrieved and used for construction. They also proposed some solutions for filling the dug holes in mining sites [22]. Because of the production process in the magnetite and polycom plants, both dry and wet tailings are produced in Golgohar Mining and Industrial Company. In the time of data collection, the total amount of dry tailings produced by the magnetite plant was 5282108 tons, while the overall amount of wet tailings produced by the polycom plant was 1845790 tons. The first step in managing such wastes is identifying their compositions. As indicated in Table 4, the main ingredients of dry tailings produced as a result of iron ore processing in Golgohar Mining and Industrial Company are quartz, manganese oxide, iron oxides, aluminum oxide, calcium carbonate, sulfur, potassium oxide, sodium oxide, titanium oxide, phosphorus, chromium oxide, barium oxide, and chromium oxide. On the other hand, the major components of wet tailings include quartz, manganese oxide, iron oxides, calcium carbonate, aluminum oxide, sulfur, sodium oxide, potassium oxide, phosphorus, titanium oxide, barium oxide, and chromium oxide. Thus, the constituent ingredients of dry and wet tailings are more or less similar. The average LOI in dry and wet tailings were 10.8 and 11.3, respectively. Table 4 illustrates the LOI percentage of dry and wet tailings. Nouranian et al. investigated the applicability of Golgohar mining tailings in other industries. They demonstrated that iron ore processing would yield quartz, manganese oxide, aluminum oxide, iron oxides, potassium oxide, calcium oxide, titanium oxide, sodium oxide, and sulfur oxide, with their proportion respectively being 38.6%, 19.15%, 14.04%, 13.7%, 5.55%, 2.08%, 1.66%, 1.17%, and 0.35%. Their average LOI was reported to be 4.2 [23]. The components that were identified in dry and wet tailings in the current study are relatively similar to those registered in other studies. The discrepancies can be attributed to difference in the composition of the raw ore that is fed into the plants. Given their ceramic engineering properties, these components can be directly used in manufacturing tile, brick, and glass-ceramic used in insulating buildings. Furthermore, because of their manganese oxide, processing tailing can constitute 15% of the compound used as cement furnace feed. Uchechukwu and Ezekiel examined the possibility of using iron ore tailings of a mine in Itakpe, Nigeria, in concrete manufacturing. They found that the ingredients of iron ore tailings included quartz (71%), iron oxide (15%), aluminum oxide (2.62%), calcium carbonate (1.2%), manganese oxide (0.3%), sodium oxide (1.2%), titanium oxide (0.2%), potassium oxide (0.08%), and sulfur oxide (0.03%). They discovered that using iron ore tailings in concrete manufacturing can improve the efficiency and compressive strength of concrete. In addition they argued that iron ore tailings can be used as a delayer in concrete manufacturing in warm climate [24]. Das et al. investigated the applicability of iron ore tailings and concluded that they can be used in manufacturing high quality floor tile and wall brick. These tiles and bricks will have more density, hardness, and strength in comparison with commonly used ones and their manufacturing is economically more justified [25].

Conclusion

The majority of industrial wastes produced in the extraction and processing sectors of Golgohar Mining and Industrial Company (save for mining tailings in the two sectors) can be recycled. Thus, it is essential to pay more attention to recycling in such industries. Improving production processes can significantly reduce the amount of wastes originally produced; hence, a crucial step for managing such wastes. Mining tailings in the processing sector constitute a major proportion of produced solid wastes in iron ore mining. Therefore, further studies should be conducted to suggest more efficient ways of retrieving iron during the processing stage, hence decreasing produced wastes. On the other hand, stakeholders should try to utilize other constituent ingredients of such wastes as raw materials for other industries. By doing so, the problems of such wastes (e.g. lack of enough depositing space and environmental problems) will be eliminated to a large extent.

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Conflict of interest

No conflict of interest has been stated by the authors.

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