

# Insight into an Integrated Evaluation of Unmitigated Disposal Options for the Largest Waste Disposal Site in Tehran Using Rapid Impact and Sustainability Assessment Method



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## Abstract

This study integrated the rapid impact assessment matrix (RIAM) analysis and the mathematical sustainability modeling to evaluate disposal options so as to find the most appropriate and practical unmitigated option for the main waste disposal site in Tehran, Iran. RIAM analysis was used to assess environmental impacts of five potential disposal options followed by determination of sustainability for each option. RIAM analysis results indicated that option 5 (i.e., composting) had the least negative cumulative impacts on the environmental score value of -481 among the studied options. Incineration of wastes, option 4, was found to be the least favorable option mainly due to the high relevant costs and emission of air pollutants. Option 3, sanitary landfilling, was found to have fewer negative impacts compared to the options 1 (open dumping), 2 (land burial), and 4. It was also found that none of the examined options were sustainable in unmitigated state; however, results indicated that option 5 was the most favorable one in terms of sustainability with an obtained sustainable value of -0.126, which was the lowest value of unsustainability found in the present study. Calculated values of environment for the evaluated options in unmitigated state were not sufficient enough to compensate for the corresponding values of human needs and interests. Finally, option 5 followed by option 3 were suggested as alternative disposal approaches for the current methods in unmitigated state to reduce negative environmental impacts of waste disposal.

**Keywords:** Environmental impact assessment, Municipal waste disposal, Sanitary landfill, Rapid impact assessment matrix, Sustainability

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## 1. Introduction

Selection of proper waste disposal strategy has long been a challenging environmental issue in developing countries. Rapid population growth and shift to urbanization in such countries led to the elevated generation of municipal solid wastes (MSW) in recent years. The increasing amount of urban wastes produced in such regions is not well managed in most cases due to the lack of an integrated solid waste management system and appropriate techno-economical infrastructures. The highest fraction of MSW management systems (ca. 80%) is allocated to the collection and transportation of MSW in developing countries (1), resulting in the lack of sufficient financial resources for the disposal stage and complicating making decisions on choosing the sound disposal options.

Selecting any waste disposal options may exert various impacts such as human health effects resulting

from emission of air pollutants, particulate matters, socioeconomic outcomes, climate change impacts caused by emission of greenhouse gases, potential contamination of water resources, noise, incidents, and the like (2,3). Environmental impact assessment (EIA) is the evaluation of the possible positive or negative impacts that a proposed project or development may have on the environmental components. Various factors need to be taken into account for EIA process of a given project such as socio-economic, cultural, and human health impacts (4,5). The main objective of the EIA projects in the context of MSW disposal sites is to identify the actual situation of a given disposal site and to implement the appropriate strategies to improve the environmental quality and mitigate contamination caused by waste disposal sites (6). The impact assessment of waste disposal sites should be conducted using an appropriate method in order to minimize the negative impacts of such sites on the

environmental components (7). Rapid impact assessment matrix (RIAM) is one of the successful tools to organize, analyze, and represent the findings of an integrated EIA which can be used for assessment of waste disposal sites (6,8). RIAM is a simple, structured, and flexible method allowing re-analysis and in-depth analysis of selected environmental components precisely and rapidly, making it a powerful tool for executing and evaluating EIAs (9). Furthermore, making multiple runs to compare different alternatives is possible using RIAM which can also be considered as makes it an attractive tool for strategy planning in solid waste management. The literature documents the applicability of RIAM for the assessment of MSW management systems for various environmental purposes (10-13). In addition, from the sustainability perspective, it is important for an option to be capable of achieving sustainable development goals. Sustainability of options can be evaluated using different methods. The mathematical model of sustainability (MMS) used in the present study was adopted from Phillips (14).

Both RIAM analysis method and MMS have been tested individually in the literature; however, the integration of these two methods investigated in EIA studies for disposal options in semi-arid regions. Rapid impact and sustainability assessment method can provide a reliable tool to assess both environmental impacts and the sustainability options simultaneously. As such, this study was carried out to evaluate different disposal options at Kahrizak disposal site, Tehran. In other words, the present study took up the challenge to evaluate potential impacts of practicable unmitigated options in Tehran's main disposal site, as the largest waste disposal site in Iran. Accordingly, the RIAM analysis method and MMS were integrated to provide a powerful decision-making tool in order to meet the goal of finding the most appropriate options for waste disposal at Kahrizak disposal site (Tehran, Iran) in an unmitigated state.

## 2. Materials and Methods

### 2.1. Description of Kahrizak Disposal Site

Tehran, the largest city of Iran, with a population of ca. 12.4 million has faced serious environmental problems among which solid waste management and disposal were more prevalent than others, especially in recent years. As the main destination for the urban wastes of Tehran, Kahrizak landfill which is located in a semi-arid region, has received all kinds of solid wastes for more than 60 years. Every day, ca. 8000-9000 tons of municipal wastes are collected and transferred to the Kahrizak landfill. Aradkooh landfilling and processing complex which is typically called Kahrizak disposal site is located 25 km south of the capital city of Tehran between 51°19'18"E of 35°27'52"N, with an area of approximately 1400 ha. Nearby residential areas such as Kahrizak, Baghershahr, and Chahardangeh districts are affected by this disposal

site. Waste materials are buried in layers of ca. 2-3 m, covered daily with soil and construction wastes, then partially leveled and compacted by the traffic of operating trucks at site. The elevated mountain by the waste burial in Kahrizak landfill has hit the height of ca. 60 m (15).

### 2.2. RIAM Analysis

The RIAM concept has been well defined by Pastakia (9). In this method, accurate and independent scores are obtained for each condition using a semi-quantitative value for each assessment criteria. The RIAM evaluation criteria that fall into the group (A), or group (B), representing importance to the condition and value to the situation, respectively, along with the scoring system in this technique are presented in detail by Pastakia and Jensen (16). The procedure for the RIAM method can be presented by Eqs. (1-3).

$$(A1) \times (A2) = AT \quad (1)$$

$$(B1) + (B2) + (B3) = BT \quad (2)$$

$$(AT) \times (BT) = ES \quad (3)$$

where (A1) and (A2) are the individual criteria scores for group (A), while (B1), (B2), and (B3) are the individual criteria scores for group (B). Moreover, AT, BT, and ES are the results of multiplication of all (A) scores, the result of summation of all (B) scores; and the environmental score for the condition, respectively (16).

### 2.3. Assessment Criteria in RIAM Analysis

The judgments on each component are made in accordance with the criteria and scales presented in Table 1. Beneficial impacts have positive values and adverse impacts have negative values as reflected in (A2).

### 2.4. Environmental Components in RIAM Analysis

The evaluation process by RIAM focuses on four categories of environmental components which are defined as follows:

- Physical/Chemical (PC): It covers all physical and chemical aspects of the environment.
- Biological/Ecological (BE): This category includes all biological aspects of the environment.
- Sociological/Cultural (SC): It encompasses all human aspects of the environment, including cultural aspects.
- Economic/Operational (EO): This category quantitatively identifies the temporary or permanent economic consequences of environmental change.

A matrix is produced for each project option using the described assessment system comprising cells that present the used criteria which are set against each defined component. The individual criteria scores are set down within each cell. ES number is then calculated using the

**Table 1.** Assessment Criteria in RIAM Analysis

Criteria	Scale	Description
A1: Importance of condition	4	Important to national/international interests
	3	Important to regional/national interests
	2	Important to areas immediately outside the local condition
	1	Important only to the local condition
	0	No importance
A2: Magnitude of change/effect	+3	Major positive benefit
	+2	Significant improvement in status quo
	+1	Improvement in status quo
	0	No change/status quo
	-1	Negative change to status quo
	-2	Significant negative disbenefit or change
B1: Permanence	1	No change/not applicable
	2	Temporary
	3	Permanent
B2: Reversibility	1	No change/not applicable
	2	Reversible
	3	Irreversible
B3: Cumulative	1	No change/not applicable
	2	Non-cumulative/single
	3	Cumulative/synergistic

Note. RIAM: Rapid impact assessment matrix. Source: (9,16).

formulae given previously and then recorded. ES values and the typical range bands currently used in RIAM are given in Table 2.

There are various approaches available for MSW disposal ranging from open dumping to sophisticated disposal options. Evaluation of the scenarios for Kahrizak disposal site mainly focused on the avoidance of further adverse environmental impacts and improving the quality of life for the local community. With regard to the realistic situations/limitations of MSW disposal in Tehran, five disposal approaches were selected. RIAM analysis has been run for the following disposal scenarios based on the above-mentioned environmental components:

1. Open dumping (OD): Option 1 was taken as the baseline situation.
2. Land burial (LB)
3. Sanitary landfilling (SL)
4. Incineration followed by sanitary landfilling of the residual wastes (ISL)
5. Composting of organic wastes followed by sanitary landfilling of the residual wastes (CSL)

A questionnaire survey was conducted based on all the following components for each option. People living close to the disposal sites, municipality officials, and environmental experts were selected as target groups to

complete the questionnaire survey. It must be noted that all the scenarios were estimated based on their unmitigated state (i.e., without considering any environmental management plan). Field trips and investigations were carefully carried out around Kahrizak disposal site and the adjacent composting plant to gain better insights regarding designation of each environmental component. Results obtained from the questionnaires in the form of mean values are given in Table 3 for the option 1. As displayed in Table 3, nine PC components, six BE components, nine SC components, and 11 EO components were considered.

### 2.5. Sustainability

The MMS used for MSW disposal options in the present study was adopted from Phillips and Mondal. Level of sustainability was also determined for the disposal options based on the Eqs. (4-8) according to previous studies (14,18). Table 4 summarizes the equations used in the model and their descriptions.

### 3. Results and Discussion

Results obtained for the environmental components corresponding to each waste disposal scenario in Tehran, as mean values of the findings of the questionnaire survey, are presented in Table 5.

#### 3.1. Option 1: OD

Results for the RIAM analysis of option 1 is presented in Fig. 1, indicating no positive impacts of any of the specified environmental components in this study (Table 5). Soil quality deterioration is probable since land resources are directly exposed to the dumped wastes. Additionally, OD has adverse impact on water resources existing in the areas adjacent to the waste dumping site due to direct leaching of various contaminants of the generated leachate (e.g., heavy metals) which are not undergoing any treatment and/or containment. Negative impacts of OD on emission

**Table 2.** Conversion of Environmental Scores to Range Bands in RIAM Analysis

Environmental Scores	Range Bands	Description of Range Bands
+72 to +108	+ E	Major positive change/impacts
+36 to +71	+ D	Significant positive change/impacts
+19 to +35	+ C	Moderately positive change/impacts
+10 to +18	+ B	Positive change/impacts
+1 to +9	+ A	Slightly positive change/impacts
0	N	No change/status quo/not applicable
-1 to -9	- A	Slightly negative change/impacts
-10 to -18	- B	Negative change/impacts
-19 to -35	- C	Moderately negative change/impacts
-36 to -71	- D	Significant negative change/impacts
-72 to -108	- E	Major negative change/impacts

Note. RIAM: Rapid impact assessment matrix. Source: (17).

**Table 3.** RIAM Analysis Matrix for Option 1: OD

Environmental Components		ES	RB	A1	A2	B1	B2	B3
<b>PC components</b>								
PC 1	Leaching from the existing municipal solid waste disposal site	-36	-D	2	-3	2	1	3
PC 2	Contamination of surface water resources	-36	-D	2	-3	3	1	2
PC 3	Contamination of groundwater resources	-48	-D	2	-3	3	2	3
PC 4	Introduction of contaminants to the natural resources (e.g., woodlands)	-54	-D	2	-3	3	3	3
PC 5	Emission of air pollutants and greenhouse gases	-56	-D	4	-2	3	1	3
PC 6	Soil instability, erosion, and physicochemical properties	-36	-D	2	-2	3	3	3
PC 7	Noise pollution	0	N	1	0	3	1	1
PC 8	Odor emissions	-42	-D	2	-3	3	1	3
PC 9	Dust from disposal site	-32	-C	2	-2	3	2	3
<b>BE components</b>								
BE 1	Flora and vegetation	-54	-D	2	-3	3	3	3
BE 2	Wildlife	-48	-D	3	-2	2	3	3
BE 3	Biodiversity	-48	-D	3	-2	2	3	3
BE 4	Ecological cycles	-56	-D	4	-2	2	2	3
BE 5	Plant and animal habitats	-54	-D	2	-3	3	3	3
BE 6	Soil biology	-54	-D	2	-3	3	3	3
<b>SC components</b>								
SC 1	Visual and aesthetical aspects	-15	-B	1	-3	3	1	1
SC 2	Public acceptance	-42	-D	2	-3	3	3	1
SC 3	Public health	-81	-E	3	-3	3	3	3
SC 4	Development and housing projects close to the disposal site and future land use planning	-30	-C	2	-3	3	1	1
SC 5	Population density and growth	-30	-C	2	-3	3	1	1
SC 6	Employment opportunities	+10	+B	2	+1	3	1	1
SC 7	Land availability based on the projected size of disposal site	-20	-C	2	-2	3	1	1
SC 8	Life quality of nearby communities	-54	-D	2	-3	3	3	3
SC 9	Effect on tourism industry	-45	-D	3	-3	3	1	1
<b>EO components</b>								
EO 1	Investment costs	-15	-B	3	-1	3	1	1
EO 2	Operating and maintenance costs	-5	-A	1	-1	3	1	1
EO 3	Post-disposal monitoring and remedial costs	-84	-E	4	-3	3	1	3
EO 4	Labor costs	-5	-A	1	-1	3	1	1
EO 5	Energy supply requirements	-5	-A	1	-1	3	1	1
EO 6	Land requirement	-15	-B	1	-3	3	1	1
EO 7	Skill worker requirement and specialized operations	0	N	2	0	3	1	1
EO 8	Technological limitations/complications	0	N	0	0	3	1	1
EO 9	Effect on the land value in real estate market near disposal site	-30	-C	2	-3	3	1	1
EO 10	Product marketing and revenues from recycled/composted materials	0	N	3	0	3	1	1
EO 11	Revenue of nearby communities from the disposal site activities	-30	-C	2	-3	3	1	1

Note. RIAM: Rapid impact assessment matrix; OD: Open dumping; PC: Physical/chemical; BE: Biological/ecological; SC: Sociological/cultural; EO: Economical/operational.

of air pollutants and dust, threatening of vegetation and wildlife, and adverse aesthetical effects can be clearly inferred from Table 3. In general, option 1 has significant detrimental impacts on the environment.

### 3.2. Option 2: LB

Results of RIAM analysis for LB of waste were mostly

similar to those of option 1 (OD) as illustrated in Fig. 1. As demonstrated, except for the employment opportunities created for some unskilled workers at land burial site, there would be no positive environmental impacts for opting the second disposal scenario. Based on data in Table 5, environmental scores associated with the studied PC components mainly fall within the

**Table 4.** A Simplified Description of the Key Equations in the Applied Model for Evaluating the Sustainability of MSW Disposal Options

Equation No.	Model Equation	Description of Model Parameters
(4)	$S(t) = E(t) - H_{NI}(t)$	Sustainability (S), time (t), value of the environment (E), value of human needs and interests ( $H_{NI}$ )
(5)	$E(t) = \frac{\sum PC + \sum BE}{\sum PC_{max} + \sum BE_{max}}$	Physical/chemical components (PC), Biological/ecological components (BE)
(6)	$H_{NI}(t) = \frac{(\sum SC_{max} + \sum EO_{max}) - (\sum SC + \sum EO)}{\sum SC_{max} + \sum EO_{max}}$	Sociological/cultural components (SC), Economical/operational components (EO)
(7)	$E(t) > H_{NI}(t) \Leftrightarrow S(t) > 0$	The examined option is sustainable if obtained value of E is greater than $H_{NI}$ .
(8)	$E(t) \leq H_{NI}(t) \Leftrightarrow S(t) \leq 0$	The examined option is not sustainable if obtained value of E is less than or equal to $H_{NI}$ .

Note. MSW: Municipal solid wastes..

Source. (18).

**Table 5.** Summary Scores of RIAM Analysis for Different Disposal Scenarios

	Class	-E	-D	-C	-B	-A	N	A	B	C	D	E
Option 1: OD	PC	0	7	1	0	0	1	0	0	0	0	0
	BE	0	6	0	0	0	0	0	0	0	0	0
	SC	1	3	3	1	0	0	0	1	0	0	0
	EO	1	0	2	2	3	3	0	0	0	0	0
Option 2:LB	PC	0	7	1	0	1	0	0	0	0	0	0
	BE	0	6	0	0	0	0	0	0	0	0	0
	SC	1	3	3	1	0	0	0	1	0	0	0
	EO	1	0	2	2	3	3	0	0	0	0	0
Option 3: SL	PC	0	3	2	1	3	0	0	0	0	0	0
	BE	0	1	3	1	0	1	0	0	0	0	0
	SC	0	2	4	1	1	0	0	0	1	0	0
	EO	0	0	5	5	0	1	0	0	0	0	0
Option 4: ISL	PC	3	1	1	1	0	3	0	0	0	0	0
	BE	2	1	2	0	0	1	0	0	0	0	0
	SC	1	4	0	0	1	1	1	0	1	0	0
	EO	1	8	0	0	1	1	0	0	0	0	0
Option 5: CSL	PC	0	2	3	0	4	0	0	0	0	0	0
	BE	0	0	0	0	3	2	0	0	1	0	0
	SC	0	0	5	2	0	0	0	2	0	0	0
	EO	0	0	6	3	1	1	0	0	0	0	0

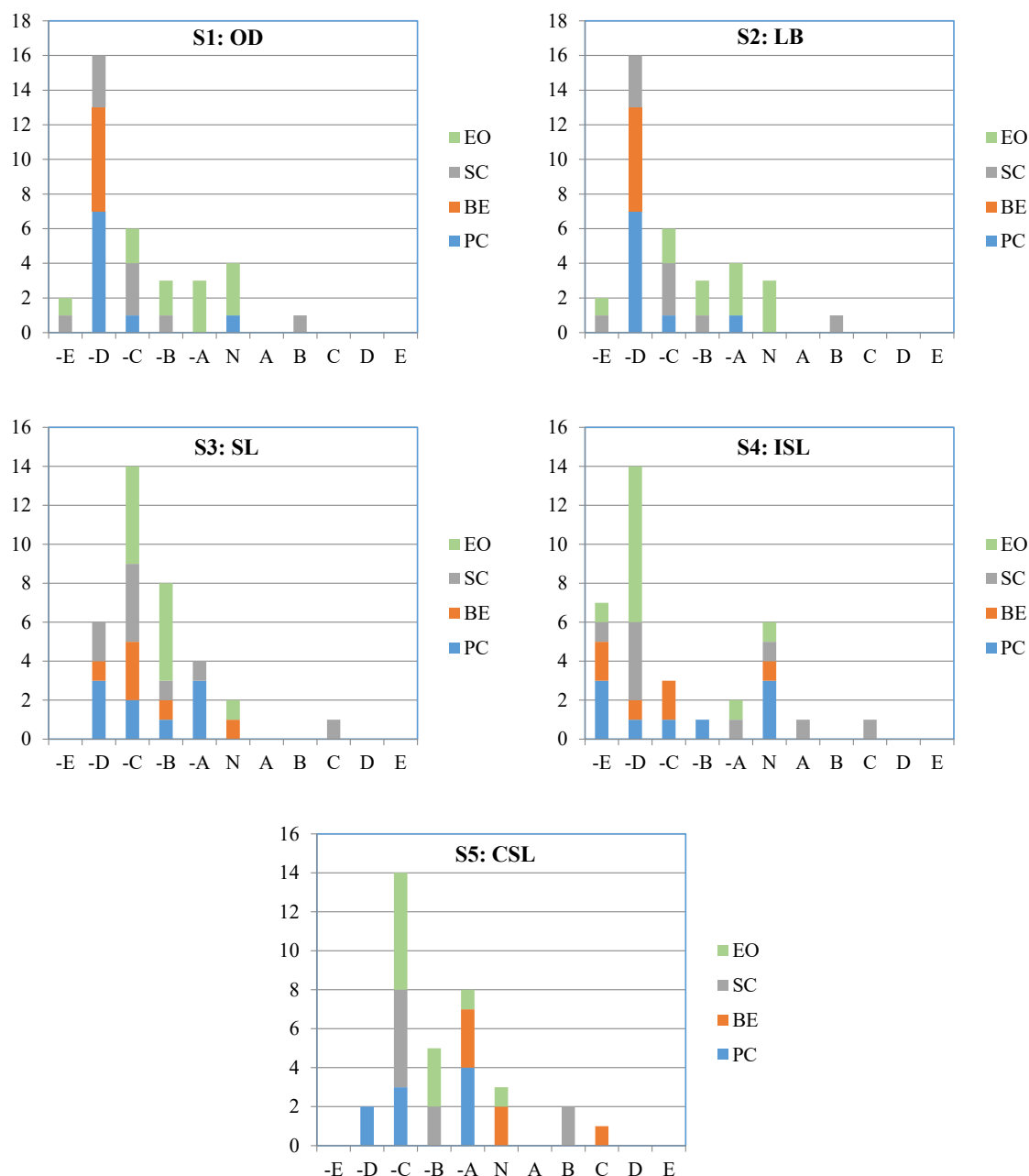
Note. RIAM: Rapid impact assessment matrix; OD: Open dumping; LB: Land burial; SL: Sanitary landfilling; ISL: Incineration followed by sanitary landfilling of the residual wastes; CSL: Composting or organic wastes followed by sanitary landfilling of the residual wastes.

range band [-D], implying significant negative impacts of land burial as a waste disposal option. Similarly, all the environmental scores for BE components fall within the same range band, namely [-D]. Major negative impacts on the public health were reported for the disposal options 1 and 2; consequently, neither option 1 nor option 2 was acceptable by the public.

### 3.3. Option 3: SL

Results of RIAM analysis for option 3 are given in Fig. 1 (Table 3). Negative impacts of WL decreased to some extent compared to the first two options; however, most of

the potential impacts of SL were still negative. SL requires significantly greater investment as well as operational and maintenance costs as compared with options 1 and 2, yielding negative impacts for EO components. Land pollution and soil remediation costs associated with landfill of wastes are greatly less than those specified for options 1 and 2. Impact of option 3 on visual and aesthetical aspects falls in the range band [-A], which is more acceptable than options 1 and 2 with the corresponding range band of [-B] (Table 5). In addition, the accumulated gas can be reused after treatment or sold as a fuel which in turn can slightly compensate for the overall costs of disposal. Other major



**Fig. 1.** RIAM Analysis for Different Options. Note. RIAM: Rapid impact assessment matrix; X-axis: Range bands; Y-axis: Number of components; EO: Economical/operational; SC: Sociological/cultural; BE: Biological/ecological; PC: Physical/chemical.

positive impacts would be reduction of threats to the flora and fauna around the disposal site.

### 3.4. Option 4: ISL

Option 4 has the most adverse  $H_{NI}$ -value among the studied options, while its  $E$ -value was slightly higher than that of options 1 and 2. Among all the examined options, the weakest unsustainability was obtained for option 4 with the lowest  $S$ -value which was mainly attributed to the severe negative impacts of SC and EO components. It can be inferred from Fig. 1 (Table 3) that option 4 has a significant negative impact on air pollution that can be

hardly prevented even in highly sophisticated incinerator plants (19-20). The pollution is mainly caused by particulate matter, SO<sub>x</sub>, NO<sub>x</sub>, dioxins, furans, and CO<sub>2</sub> which are known for their adverse effects on the environment and human health, resulting in negative impacts for most of the identified environmental components (e.g., PC, BE, and SC components). Incineration of MSW has received remarkable attention in some developed countries in recent years; however, reduction in the volume and weight of wastes through incineration is a controversial issue in many countries due to the potential adverse environmental and human health impacts (21-22). Today,



incineration of collected wastes in Tehran is proposed as a principal alternative to dumping/landfilling of wastes by some decision-makers and planners. This can be due to the fact that finding an appropriate disposal site, instead of the current disposal site at Kahrizak, is becoming more and more challenging. Results indicated that the negative impacts of waste incineration on emission of air pollutants could be severe, confirming the results reported by other authors (23). However, the potential impacts on water resources would be minimal because of significant reduction in the volume of wastes. Waste incineration residues can be disposed in sanitary landfills or reused. Reuse of incineration residues instead of virgin materials helps relieve landfill pressures while reducing demand on extraction of raw materials (24); however, environmental risks associated with their reuse must be evaluated. MSW incineration bottom ash contributes to approximately 80% of the produced solid residues in MSW incinerators (25). Option 4 (ISL) resulted in more negative impacts compared to SL in most cases. Findings also indicated that incineration of wastes is not acceptable by the public, demonstrating less acceptability than landfilling which may be attributed to the lack of planning for sources, separation of wastes, as well as high maintenance requirements associated with trapping the toxic emissions from incinerators. The evaluated environmental scores for the majority of EO components fall within the range bands [-D] and [-E] (Fig. 1, Table 5), indicating significant negative impacts mainly due to the greater investment along with the operational, maintenance, and monitoring costs compared to the other disposal options. In addition, the energy recovery from the municipal wastes generated in Tehran is hardly justifiable economically since they contain more than 65% moisture that is unfavorable in the context of energy recovery through waste incineration.

### 3.5. Option 5: CSL

Option 5 is a biological process carried out under controlled aerobic conditions during which various microorganisms including bacteria break down the organic matter in MSW into simpler substances. This process recycles various organics in MSW stream, and the decomposed material produced in this process is called compost which is usually rich in nutrients. Fig. 1 illustrates RIAM analysis results for option 5. Composting process still generates leachate which can be harmful to the water resources so that if it is not well managed, it will lead to negative impacts for PC components. Further, a moderately positive impact on employment opportunity and public acceptance was reported for disposal option 5 (Fig. 1, Table 3).

One positive impact is that, option 5 is less complicated to implement compared to both SL and incineration in many countries. Furthermore, composting of wastes is also considerably less expensive than incineration in terms of the investment and maintenance costs as well

as monitoring expenses. However, source separation is vital to be planned and implemented properly in order to make sure about the quality of the produced compost. Contamination of MSW composts with unacceptable levels of heavy metals in Iran was investigated (26), implying that extensive land areas can be affected by spreading the contaminated compost. Moreover, emission of biological aerosols from Kahrizak composting plant, Tehran, particularly at waste screening and separation units, was reported to exceed the acceptable limits set by American Society for Testing and Materials (27), implying potential adverse human health impacts. More than two thirds of the wastes generated in Tehran composed of organic matters which made composting an attractive disposal option.

### 3.6. Sustainability of the MSW Disposal Options

The values of relative environmental scores were calculated using the original ES in RIAM analysis. Total relative ES for each disposal option is given in Table 6. Data given in Table 6 were used to determine the values of E,  $H_{NP}$ , and S using the equations presented in Table 3 and the sustainability results are presented in Table 7. It can be inferred from Table 6 that none of the disposal options for Tehran are sustainable; however, option 5 followed by option 3 indicated smaller unsustainability compared to the other disposal options that is consistent with RIAM analysis results for the examined options (Fig. 1).

Model results indicate that all of the options in the unmitigated state are unsustainable which is consistent with the findings of the RIAM analysis method in the present paper. Unsustainability could be expected for the first two options. However, the rest of the options especially options 3 and 5 could have potential benefits if they are properly planned and implemented. In other words, if the options 3 and 5 are analyzed in the mitigated state (i.e., with an EMP), the options might have the potential to be sustainable; however, precise analysis is required to further clarify that. The options in an unmitigated state would require intense management, resources, and time to potentially become sustainable.

Although the options were evaluated in unmitigated state using RIAM analysis, obtaining results may raise potential uncertainties concerning the environmental and social credentials of composting. Option 5 in an unmitigated state was found to be unsustainable which is in contradiction with the widely accepted claim stating that composting is not only environmentally beneficial but also contributes considerably to the sustainable development (28,29). In other words, results of the present study seem to contradict the potential benefits and sustainability of composting as disposal option in Tehran in unmitigated state that is consistent with findings of Phillips and Gholamalifard who assessed sustainability of MSW disposal options for Tabriz, Iran

**Table 6.** Total Relative ES for the Calculated Disposal Options from the Original ES for the Environmental Components

Component	Option 1: OD		Option 2: LB		Option 3: SL		Option 4: ISL		Option 5: CSL	
	ES <sub>O</sub> <sup>*</sup>	ES <sub>R</sub> <sup>+</sup>	ES <sub>O</sub>	ES <sub>R</sub>	ES <sub>O</sub>	ES <sub>R</sub>	ES <sub>O</sub>	ES <sub>R</sub>	ES <sub>O</sub>	ES <sub>R</sub>
ΣPC	-340	632	-345	627	-217	755	-362	610	-195	777
ΣPC <sub>max</sub>	-	1944	-	1944	-	1944	-	1944	-	1944
ΣBE	-314	334	-314	334	-133	515	-273	375	10	658
ΣBE <sub>max</sub>	-	1296	-	1296	-	1296	-	1296	-	1296
ΣSC	-307	665	-295	677	-186	786	-284	688	-113	859
ΣSC <sub>max</sub>	-	1944	-	1944	-	1944	-	1944	-	1944
ΣEO	-189	999	-189	999	-203	985	-464	724	-183	1005
ΣEO <sub>max</sub>	-	2376	-	2376	-	2376	-	2376	-	2376

Note. \*ES<sub>O</sub>: Original ES; +ES<sub>R</sub>: Relative ES; OD: Open dumping; LB: Land burial; SL: Sanitary landfilling; ISL: Incineration followed by sanitary landfilling of the residual wastes; CSL: Composting or organic wastes followed by sanitary landfilling of the residual wastes.

**Table 7.** Determined Values of E, H<sub>Ni</sub>, and S for MSW Disposal Options in Tehran

Disposal Scenarios	E	H <sub>Ni</sub>	S-value	S-level
Option 1: OD	0.298	0.615	-0.317	N/A (Unsustainable)
Option 2: LB	0.297	0.612	-0.315	N/A (Unsustainable)
Option 3: SL	0.392	0.590	-0.198	N/A (Unsustainable)
Option 4: ISL	0.304	0.673	-0.369	N/A (Unsustainable)
Option 5: CSL	0.443	0.569	-0.126	N/A (Unsustainable)

Note. RIAM: Rapid impact assessment matrix; OD: Open dumping; LB: Land burial; SL: Sanitary landfilling; ISL: Incineration followed by sanitary landfilling of the residual wastes; CSL: Composting or organic wastes followed by sanitary landfilling of the residual wastes.

(30). Consistent observation was reported by Valizadeh and Hakimian where various disposal options (e.g., SL and waste dumping) were evaluated in Birjand, Iran, using RIAM. They found that composting option, with final scores of -0.5, had the least negative environmental impact, whereas, OD had the most negative environmental impact (2). Another study conducted by Gholamalifard et al on the application of RIAM in EIA of MSW landfill of Shahrekord, Iran, revealed that composting and recycling options are the first priority for Shahrekord waste disposal (31). Furthermore, composting of wastes in accompany with SL was reported to be the most appropriate option for MSW in Tabriz, Iran, based on the RIAM findings (6).

Currently, there is no indication of any environmental management plan for the presented options in place. Although development of such plan might place a significant economic burden, it would potentially improve the environmental and social situations in the vicinity of the disposal site and accordingly improve the potential environmental scores for the options. Therefore, finding realistic solutions to achieve sustainable waste management would be extremely challenging in large cities in most developing countries where a comprehensive environmental management plan is not in place. In general, establishment of proper electromagnetic pulse can alter the favorability of the examined options in this study, especially for the alternative options of 3, 4, and 5.

#### 4. Conclusion

Potential impacts of practicable unmitigated options in Tehran's main disposal site, as the largest waste disposal site in Iran, were evaluated using RIAM analysis method. The RIAM analysis results clearly indicated that OD and LB which were mainly practiced in Kahrizak disposal site, Tehran, had significant negative environmental impacts on almost all the studied components since wastes are directly dumped/buried without undergoing any treatment or proper containment. Based on the RIAM analysis results, option 4 was found to be the worst alternative even with greater accumulative negative ES as compared with options 1 and 2. The majority of the significant negative impacts occurred in the PC category for options 1, 2, and 3. RIAM analysis revealed that incineration had the greatest negative cumulative ES value of -1383, whereas the lowest negative cumulative ES value of -481 was obtained for option 5, suggesting that option 5 is the most suitable disposal option among the evaluated options. SL was shown to have fewer negative impacts compared to the options 1, 2, and 4. In addition, based on RIAM analysis results, option 5 can be regarded as the best recommended option in unmitigated state which posed the least negative environmental impacts. In general, findings of the RIAM analysis method were consistent with the results of the mathematical model for assessment of sustainability for different studied options in the present study.

Evaluation of sustainability demonstrated that none of the options were sustainable in unmitigated situation, suggesting the need for an effective environmental management plan to mitigate the produced environmental impacts. The obtained E-value and H<sub>Ni</sub>-value for the worst option (i.e., option 4) were 0.304 and 0.673, respectively, giving a weak unsustainability, whilst option 5 gained the best E-value among the examined options in this study, suggesting comparatively more beneficial impacts on PC and BE components. The lowest H<sub>Ni</sub>-value was also obtained for option 5, indicating fewer negative impacts



on SC and EO compared to the other disposal options. However, the beneficial environmental impacts were not at such a sufficient level that can compensate for the adverse human impacts of the option which appeared in the  $H_{NI}$ -value.

The results of the present study can be used as a baseline for evaluating waste disposal options in semi-arid regions with comparable techno-socio-economic situation. The potential impacts and sustainability or unsustainability of the mitigated and well-managed options can also be reevaluated using the RIAM analysis method as well as the MMS.

#### Conflict of Interest Disclosures

The authors declare that there is no conflict of interest regarding the publication of this paper.

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