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Research Article

FMEA and AHP Methods in Managing Environmental Risks in Landfills: A Case Study of Kahrizak, Iran

Benyamin Sadeghi [a,*], Mansour Sodagari [b], Hossein Nematollahi [c], Hamed Alikhani [d]

[a] Industrial and Manufacturing Engineering, University of Wisconsin-Milwaukee, Milwaukee, USA
[b] Construction Management, University of Florida, Gainesville, USA
[c] Faculty of Environment, University of Tehran, Tehran, Iran
[d] Interdisciplinary Engineering, Texas A&M University, College Station, USA

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Abstract
As waste disposal centers are the hub of pollutants, the emission of these pollutants and their byproducts such as smell and dust, which are produced during the disposal process, may cause public grievances over waste disposal. The daily production of more than 8,000 tons of urban waste in Tehran has caused problems for the Tehran municipality. The Kahrizak landfill in Tehran has weaknesses, which leads to risks and citizens' discontentment as well as environmental issues and hazards. Due to population growth in megacities and the per capita increase in waste production, the need for a more suitable landfill has been one of Tehran's officials' concerns. In this study, after identifying risks at Kahrizak using a survey, the failure mode and effects analysis (FMEA) method and analytic hierarchy process (AHP) are integrated to prioritize these risks. After the distribution of a questionnaire among 130 waste management experts, 22 risks were identified. Then, with the scoring of the risk severity, the probability of occurrence, and the detectability potential, the risk priority number (RPN) was calculated, and the risks were prioritized based on RPN. The results show that the following risks had the highest priority: change in land use, distance to the city limits signs, and distance to the airport. Finally, nine corrective actions were identified in a follow-up survey, which was distributed among 92 experts, to address the landfill's risks in Tehran and other similar megacities.
Keywords: Environmental risk, landfill waste, Risk management, FMEA, AHP

Introduction

The rapid increase in population in developing countries has resulted in significant solid waste, consequently creating a local and global environmental challenge (Fan et al., 2018; Paul et al., 2019). Tehran is the metropolis and the capital of Iran that has a population of 9.1 with a growth rate of 1.3% since 2015 (WPR, 2020), generating 5,800 tons of waste daily (Abdoli, 2020), where municipal solid waste generation had recently increased by 10% in a five-year period (Malmir & Tojo, 2016). Lack of proper waste management and the relatively high quantity of hazardous materials in the solid waste caused solid waste management a severe issue in Tehran (Rupani et al., 2019).

Landfill site refers to facilities into which waste is carried from where it was first produced and then buried in soil that has been treated so that it will not cause any environmental or

* Corresponding author E-mail: bsadeghi@uwm.edu

sanitary threats at the burial site. Waste burial is a common waste disposal method that aims to minimize health-related risks and environmental hazards (Ahluwalia & Patel, 2018; Paul et al., 2019; Yousefian et al., 2020). Sanitary waste burial is the last priority in the hierarchy of comprehensive waste management and is considered a complementary choice along with other managerial steps. Nevertheless, with the employment of other comprehensive waste management preferences, like reducing waste production in the first place, recycling and restoring, and most ideally changing waste to generate energy, some of the waste is leftover, and its disposal through the sanitary waste burial method is inevitable. Even using a rotary kiln to incinerate waste leaves behind about 10% of the total waste size in ash form, leaving no choice but to bury it (Ahluwalia & Patel, 2018).

In landfill sites, the leakage and penetration of leachate, which contains toxic compounds and pollutants, lead to groundwater contamination and causes various environmental issues and health problems. Davoli et al. (2010) investigated and assessed the health and hygiene-related risks of citizens in Italy who lived in the vicinity of landfills and were exposed to soil, water, and air pollution. The results of that study indicated an excessive release of carcinogenic chemicals in such places. Ihedioha et al. (2017) studied soil contamination near municipal waste. The ecological risk assessment revealed that cadmium was the only metal imposing a potentially high risk to humans.

Technical criteria and principles regarding the disposal of waste material have not been observed in many of the landfill sites, and waste disposal methods have been mostly unsanitary and unsafe (Ahluwalia & Patel, 2018). In 2020, Yousefian et al. investigated and assessed landfill workers' health and hygiene exposed to the inhalation of o benzene, toluene, ethylbenzene, xylenes (BTEX). These researchers' findings showed that non-carcinogenic does not threaten landfill workers, while the carcinogenic risk for workers' health is worrying due to exposure to a high amount of BTEX (Yousefian et al., 2020). Also, due to the formation of a high amount of methane in landfills, the occurrence of explosions and fire is highly probable (Amini et al., 2017). Consequently, the occurrence of environmental hazards is not far-fetched.

The landfill site's location plays a crucial role in the waste disposal network and is considered part of the new comprehensive waste management approach. In 2013, to find a suitable landfill site, Gorsevski et al. conducted a Macedonia study based on the GIS multi-criteria decision-making analysis method. They concluded that landfills' location is, to a great degree, influenced by public and political forces, which is subject to careful analysis and investigation (Gorsevski, Pece V., et al., 2013). In 2018, using the extended VIKOR method, Wu et al. studied the most optimal site location for the waste-to-energy (WtE) plant. The results obtained from this study indicated that public satisfaction policy and the environmental factor outweighed other factors (Wu et al., 2018).

In recent years, due to various industries' development, all kinds of environmental risks have increased. Therefore, the employment of some methods to reduce, eliminate, and control these risks is deemed vital. Risk management is a systematic procedure for identifying, analyzing, and responding to risks. Risk management seeks to maximize the probability and impacts of favorable incidents and minimize the probability of unfavorable consequences and negative impacts (PMBOK, 2017). Risks cannot be entirely eliminated, but they can be reasonably mitigated by adopting appropriate mitigation strategies (Sadeghi et al., 2016). Environmental risk management is a systematic procedure for identifying and investigating environmental hazards and detrimental consequences, risk assessment and analysis, and optimal risk control.

Various research methods have investigated the environmental risks of landfills. To identify and evaluate the environmental impacts of leachate current in a place located in north China, Xing et al. (2013) compared strategies of leachate current and its drainage and evaporation using four scenarios from the EASEWASTE model. Dangi et al. (2015) investigated the environmental impacts of landfill sites in Nepal by interviewing experts and concluded that it was necessary to rectify assessments and maintain quality and accuracy in waste management to mitigate the impacts of landfill sites.

De Souza and Carpinetti (2014) utilized failure mode and effects analysis (FMEA) to prioritize waste management strategies and calculated their risk priority numbers (RPN) by assigning occurrence, severity, and detection rates to each risk. They identified 8 waste modes in manufacturing and 10 waste modes in service and administrative flows by reviewing the existing literature body. Sutrisno et al. (2016) proposed a waste priority number (WPN) to rank waste maintenance operations. They applied AHP to quantify the maintenance causes weights. They calculated WPN by multiplication of detectability of waste cause, probability of occurrence of waste, rectification difficulty, and expected cost. Sutrisno et al. (2015) developed a modified FMEA model for calculating the risk of maintenance waste. They added new dimensions to the model to evaluate risk criticality of maintenance waste. These new dimensions are the preventability and controllability scale to mitigate the limitation of directionality.

The present study identified the risks, hazards, and obstacles present in the management of Kahrizak landfill, the main landfill site of Tehran, and specified the highest risk factors using the integration of FMEA and AHP methods. Then corrective actions to mitigate these risks are presented. Since hazards and risks in the Kahrizak landfill management hub have not yet been investigated, this study will explore them in detail. The results of this study can be used for managers of Tehran's waste disposal network to monitor Kahrizak continuously and to ensure it always has the highest efficiency and functionality in line with sustainable development.

Material and Methods

Study Area

As one of the most populous megacities globally, Tehran, with a daily waste production of 8000 tons, requires proper management in terms of waste disposal and burial. In Tehran, 8000 tons of urban waste is collected daily from an area of 100 square kilometers, of which 35% is dry waste, and the other 65% is wet. Up until several years ago, dry waste accounted for 30% of the total waste in Tehran. The main disposal concern of waste management is wet waste because dry waste is incinerated and used to generate electricity in most parts of the world. Since the bulk of waste in Tehran comprises wet waste, the waste management organization has been trying to extract the highest compost from this wet waste. Tehran has three waste-producing units, and these producers drain their garbage in 70000 reservoirs. Twelve companies with about 15500 staff and 800 vehicles are in charge of the waste organization.

Tehran's total waste is carried to Kahrizak landfill by two hundred 20-ton trailers, and each of these trailers transports waste three times a day. The capacity for waste sorting and processing in Kahrizak is currently 3000 tons per day. However, malfunctioning in these units has been reported. 3500 tons out of the total waste is buried outright, which is inevitable given the high amount of waste production and population growth. Attempts have been made to attract investment in electric power generated from waste.

Research Method

The intended research method was initiated from many pieces of evidence reported on social media, news, journal papers, and other sources about the Kahrizak landfill from universities and relevant organizations. Some of its environmental and health-related risks can be identified by the public, such as the unpleasant smell, congestion of birds of prey and other animals, traffic, and pollution on the routes towards the landfill. In contrast, others need exhaustive scrutiny and engineering tools, e.g., water and soil pollution. Then, according to the analysis of the data collected and the results obtained from the investigation of the environmental state of the Kahrizak waste management center, environmental risks are identified and evaluated using the FMEA method. Finally, risk management solutions based on the severity and probability of the risk are presented. It is clear that there are various methods for the identification and evaluation of environmental risk, each with its benefits and drawbacks. In this research, considering limitations in terms of time and budget and a greater tendency to achieve qualitative results, the FMEA method is used for environmental risk evaluation. The study followed three steps:

Step 1: the required information was collected by conducting a field visit, going to Kahrizak waste management center, meeting with the officials there, and asking them questions. Some investigations about the current status of waste management, field visits, and interviews were conducted to assess environmental risk in this study. By reviewing previous studies, research papers, executive reports from waste management authorities, experts' interviews, and the authors' observations, 37 risks were identified.

Step 2: The 37 risks were listed in the questionnaire and examined in the first survey, which was distributed among 130 experts in the area of solid waste. For each risk, were calculated, and RPN for each of the risks was obtained. Based on the results of the survey and values assigned to the three criterions-severity (S), occurrence (O), and detection (D)-RPN numbers were calculated for all 37 risks. After accomplishing the first survey, the authors evaluated the survey results and determined a threshold for the acceptable RPNs. An RPN of lower than five was considered an acceptable risk score. The risks listed in Table 5 with an RPN number equal and higher than five need corrective actions. The risks with an RPN of lower than five were excluded. As a result, the rest of the risks with an RPN lower than five did not justify taking any corrective actions or to spend a budget on improving their RPN and consequently were excluded from the list. For example, the risk of contagious diseases spread-out within the region was calculated four due to evacuation of the area and thus was eliminated from the second survey. Out of the 31 risks, 22 risks with the highest RPN scores were selected and filtered out. At this stage, the analytic hierarchy process (AHP) was used to determine the identified risks' severity. The failure modes and effects analysis (FMEA) were used to prioritize them to assess the risks.

In the first survey, the participants were asked to answer three types of questions, which are as follows: (1) Two open questions were asked to identify risk causes and effects. (2) One multiple question inquired about the effect of risks on the five target groups, including citizens' satisfaction, citizens' health, local economy, environmental impacts, and safety. (3) The participants were asked to assign scores to three criteria allotted to each risk: probability, detection rate, and severity. A scale of 0 to 10 was defined to rank the risk criteria.

Step 3: The second survey was conducted among 92 experts to identify solutions to the 22 risks. Twenty-three corrective actions were identified by reviewing literature and interviews with experts. In the second survey, the participants were asked to select a solution from the list or suggest any potential corrective actions based on their expertise and knowledge. There were five choices to evaluate the effectiveness of each of the 23 corrective actions: (1) strongly disagree, (2) disagree, (3) neutral, (4) agree (5) strongly agree. Among these 23 solutions, 92% of the participants agreed or strongly agreed on nine proposed corrective actions. To choose the most effective solution for each risk, the corrective actions with an average score of 3 or lower were omitted. Nine solutions received an average score higher than 3. As a result, the rest of the corrective actions were excluded from the list as they were not frequently addressed, and effective managerial strategies were put forth based on the investigation results.

Surveys were distributed both in person and via Email based on a non-random sampling method and the participants' availability. The participants were faculty and graduate students at the University of Tehran with relevant majors or fields of study. The questionnaire was also distributed to experts at Kahrizak landfill and related organizations such as the Waste Management Organization of Tehran Municipality. The information provided by the engineer participants can be more reliable (Forati et al., 2015). The second survey was sent to all the participants in the first one. However, some did not respond to the Email or were not available to hand in the second survey. Therefore, only 92 of the participants responded.

The questionnaire was validated using SPSS. At first, a pretest was designed. The questionnaire was sent to 20 people outside the University of Tehran and Kahrizak landfill. They were students and faculty at Amirkabir University in environmental engineering and environmental science majors and randomly selected. SPSS was utilized to analyze the data, and the validity of the first survey results was checked with Pearson Product Moment Correlations. Besides, the test of reliability was done by using the alpha measure.

Failure Modes and Effects Analysis (FMEA)

Failure modes and effects analysis (FMEA) technique is a preventive and systematic method whose primary purpose is specifying points and paths in which a process or a system's design may go wrong and disrupt the entire system's efficiency. After spotting these failure modes, the causes of these are discussed, and ways to prevent them are investigated. This step is carried out so that the FMEA 's output gives a reliable design to the design engineer and enhances the system's safety protection (Stamatis, 2003). The purpose of FMEA in a process or a product is to prevent incidents. In other words, FMEA reduces many costs through the optimization of processes and products. Since cost reduction is made in the early stages of process development, alterations are relatively simple and cost-effective (Stamatis, 2003).

FMEA is utilized in risk assessment to identify and prioritize the risks based on their probability of occurrences, causes, and impacts. To that end, three variables are used in this method:

(1) Severity (S): It represents the potential impact of a failure mode or seriousness degree of failure. Table 1 in the appendix shows the criteria for ranking severity ranging from 1 to 10

(2) Occurrence (O): It reflects the frequency of a failure (see Table 2 in the appendix).

(3) Detection (D): It measures the capability of detecting a failure before its occurrence (see Table 3 in the appendix).

Tables 1 to 3 in the appendix are modifications of the original tables found in Stamtis (2003). Risk Priority Number (RPN) is calculated by multiplying the severity, occurrence, and detection. Based on Equation 1, RPN ranges from 1 to 1000.

$$RPN = S * O * D \tag{1}$$

Table 1. Severity ranking criteria

Severity	Criteria	Ranking
None	No effect.	1
Very Minor	Very Minor effect on system performance/customer	2
Minor	Minor effect on system performance/customer	3
Very Low	Very Low effect on system performance/customer.	4
Low	Low effect on system performance/customer.	5
Moderate	Moderate effect on system performance/customer.	6
High	Damage system but still operational and safe	7
Very high	Stop system operation. No hazardous effects, safe	8
Hazardous with warning	Maybe hazardous effects, system failure with a warning.	9
Hazardous without warning	Hazardous effects, complete sudden failure, safety issues	10

Table 2. Occurrence ranking criteria

Occurrence	Criteria	Ranking
Extremely unlikely	Occurrence is unlikely	1
Remote	Occurs every 5 years	2
Very Low	Occurs every 2 years	3
Low	Occurs every year	4
Moderate	Occurs every 6 months	5
Occasional	Occurs every 3 months	6
High	Occurs every month	7
Very high	Occurs every week	8
Frequent	Occurs twice a week	9
Unavoidable	Occurs once or more every day	10

Table 3. Detection ranking criteria

Detection	Criteria	Ranking
Almost certain	Current monitoring almost always will detect the failure	1
Very high	Very high likelihood current monitoring will detect the failure	2
High	High likelihood current monitoring will detect the failure	3
Moderately high	Moderately high chance current monitoring will detect the failure	4
Moderate	Moderate likelihood current monitoring will detect the failure	5
Low	Low likelihood current monitoring will detect the failure	6
Very low	Very low likelihood current monitoring will detect the failure	7
Remote	Remote likelihood current monitoring will detect the failure	8
Very remote	Very remote likelihood current monitoring will detect the failure	9
Absolutely uncertain	Monitoring will not detect the failure	10

Table 4. AHP to FMEA conversion criteria

AHP Ranking	Criteria	FMEA Ranking
0-0.01	No effect.	1
0.011-0.02	Very Minor effect on system performance/customer	2
0.021-0.03	Minor effect on system performance/customer	3
0.031-0.04	Very Low effect on system performance/customer.	4
0.041-0.05	Low effect on system performance/customer.	5
0.051-0.06	Moderate effect on system performance/customer.	6
0.061-0.07	Damage system but still operational and safe	7
0.71-0.08	Stop system operation. No hazardous effects, safe	8
0.081-0.09	Maybe hazardous effects, system failure with a warning.	9
0.091-0.1	Hazardous effects, complete sudden failure, safety issues	10

Analytic hierarchy process (AHP)

The Analytic Hierarchy Process (AHP) is one of the most comprehensive systems designed for multi-criteria decision-making. This technique formulates the problem hierarchically and can take different qualitative and quantitative criteria into account. This process involves different choices in decision-making and conducts sensitivity analysis (Saaty, 1990). AHP is based on pairwise comparisons that can rate judgments (Amini et al., 2020). It also shows the amount of compatibility and incompatibility of a decision, which is one of the benefits of this multi-criteria decision-making method. The employment of this method entails taking these four major steps (Saaty, 1990).

a) Modeling

In this step, the problem and the decision-making objective are drawn hierarchically out of the decision's elements, which are in close contact. The decision-making elements include decision-making indices and decision-making alternatives. AHP breaks down a multi-indices problem into a hierarchy of levels. The upper level indicates the main objective of the decision-making process. The second level shows major key indices that may break down to ancillary indices at the next level. The last level presents the decision's alternatives.

b) Preferential judgement (pairwise comparisons)

In the second step, comparisons are made between different decision alternatives according to each index, followed by judging the decision's index's importance through pairwise comparisons. After designing the hierarchy of the decision's problem, the decision-maker must create a collection of matrices that numerically measure the preference or relative importance of indices against each other or each decision's alternative against the other alternatives to indices. This is done by making pairwise comparisons and allocating numerical values representing the preference or the importance between every two elements of a decision. In doing this, alternatives with i indices are usually compared with j indices alternatives (see Equation 2).

c) Calculating relative weight:

In AHP, each level's elements are compared pairwise with their relevant element on a higher level, and their weights are calculated. These weights are called relative weights. Specifying the weight of the decision's elements in relative terms through a set of numerical calculations: the next step in AHP is conducting the calculations required to determine the priority of each of the decision's elements using the information from pairwise comparisons matrices. The summary of the mathematical operation in this phase is as follows. The sum of numbers in each column of pairwise comparisons matrices should be calculated, and then divide each column's element by the sum of the numbers in that column. The new matrix obtained this way is called a normalized comparisons matrix. The mean of numbers representing normalized comparisons matrix in each row is calculated. The resulting mean shows the relative weight of the decision's elements with matrix rows.

d) Combining relative weights:

To rank the decision's alternatives, in this step, each element's relative weight must be multiplied by the relative weight of higher elements to calculate its final weight. By doing this for each alternative, the amount of final weight is obtained, called Absolute Weight.

Consistency in judgements

The inconsistency ratio is a tool that specifies consistency and shows the extent to which priorities resulting from comparisons can be trusted. Although the comparison of two single alternatives seems easy, it gets complicated in the case of the pairwise comparison of alternatives. To address this complexity, the consistency ratio is used. Experience has shown that if the inconsistency ratio's value is smaller than 0/10, the consistency of comparisons is acceptable. Otherwise, comparisons need to be revised. The following steps are taken to calculate the inconsistency ratio:

Step 1. Calculating weighted sum vector: multiply pairwise comparisons matrix by column vector *relative weight*, and the new vector obtained this way is called the weighted sum vector (Equation 2).

$$A = \begin{bmatrix} a_{11} & \dots & a_{12} & \dots & a_{1n} \\ \vdots & & \vdots & & \\ a_{21} & \dots & a_{22} & \dots & a_{2n} \\ \vdots & & \vdots & & \\ a_{n1} & \dots & a_{n2} & \dots & a_{nn} \end{bmatrix} \qquad a_{ii=1},\ a_{ji} = 1/a_{ij},\ a_{ij} \neq 0. \tag{2}$$

Step 2. Calculating consistency vector: divide the elements of the weighted sum vector by the relative priority vector. The resulting vector is called the consistency index.

Step 3. Calculating λ_{max}, the mean element of the consistency vector λ_{max} is obtained.

$$A * w_i = \lambda_{\max} * w_i, \quad i = 1, 2, \ldots, n. \tag{3}$$

Step 4. Calculating consistency index: consistency index is defined as below:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{4}$$

n: includes the number of alternatives in a problem

Step 5. Calculating the consistency ratio: consistency ratio is obtained by dividing the consistency index by the random index. The consistency ratio of 0/1 or smaller indicates consistency in comparisons.

$$CR = \frac{CI}{CR} \tag{5}$$

AHP generates a number between 0 to 1 as the severity weight for each risk, and the weights of all the risk severities add up to 1. To convert the results of AHP to the severity scale proposed in table 1 in the appendix, a new ranking method is used, shown in Table 4 in the appendix. For example, the weight of the groundwater pollution calculated by AHP is 0.075, and according to Table 4 the corresponding FMEA severity ranking of this risk is 8.

Results and Discussion

In this section, the risk factors, risk causes, and risk impacts, together with the existing recommendations for mitigating these risks, are discussed.

Risk Prioritization

Utilizing the questionnaire results, which were distributed among 130 of the experts in the field of environmental engineering and waste management, 22 risks were identified in the landfill. Five target groups were extracted from the survey results, including citizens' satisfaction, citizens' health, local economy, environmental impacts, and safety. In Table 5, the identified risks are presented in the first column. The causes of these risks are shown in the second column. To mitigate these risks, corrective actions should be adopted that will eliminate the risk causes. Since each risk will impact target groups such as people, animals, plants, and the environment, identifying these groups is vital for evaluating the severity of the risks. In the third column, the target groups impacted by each risk are shown. Based on the survey results, the occurrence probability of each risk is calculated. The score for each risk is shown in the fifth column. The severity weights for each of the risks is presented in the fourth column. The detection score for each risk was calculated based on the results of the survey. The sixth column shows the detection capability for each of the risks. Utilizing equation 1, risks can be prioritized based on their RPN that takes three parameters of the risks: severity, occurrence, and detection.

One shortcoming in the previous research studies was that the risk severity was not calculated based on the comparison. In this paper, each risk's severity is computed using the AHP method considering target groups impacted by each of the risks. The AHP method is efficient in pairwise comparisons, and the risks were weighed based on their importance relative to each other. Therefore, AHP can be an effective method for measuring each risk's severity compared to other risks. By doing so, a more realistic number for calculating the risk impacts on the five target groups, including citizens' satisfaction, citizens' health, local economy, environmental impacts, and safety, is provided. AHP can reduce the effects of confounding variables. Some risks impact target groups in a short time, while others impact in a longer period. To rank the risks, a realistic comparison is required. The five proposed criteria provide a reasonable comparison basis for managers' judgement. For example, dust production's health and environmental impacts because of improper disposal at Kahrizak landfill and wind directions are impacted the target groups almost every day, and any planning and investment to reduce these negative impacts can be effective quickly. However, other types of risks can impact target groups in a longer course of time. For example, the impacts of leachate infiltration to the groundwater happen in a long time and mitigate the risks of their potential health and environmental impacts time-consuming processes. Thus, we used AHP to rank risk severity on a comparative basis to reduce the impact of time as a confounding variable.

Regarding the results, another issue deserving attention is that the existence of the Kahrizak landfill has posed a menace to the Imam Khomeini airport. The presence of birds with high density in these areas threatens the course of flights and causes visual pollution. Passengers' complaints about inhaling unpleasant smells in the vicinity of Imam Khomeini airport have been recurrently reported. Local people's satisfaction, which is the fifth priority, overlaps with distance to the city limit as the second priority.

Regarding the results obtained, it is observed that 3 risks with the highest priority are 'change in land use, distance to the city limits, and distance to local airports' respectively. Also, 3 risks with the least priority are distance to hospital centers, the existence of bird habitat, and noise pollution. Since a change in land use can play a significant role in reducing the value and changing the use of neighboring areas, this risk must be given top priority in the planning scheme of Kahrizak managers. Also, as concerns about earthquake hazards have escalated in recent years, due measures must be taken to purify the leachate produced and decrease its pollution burden. Citizens' dissatisfaction is another issue about which various reports have been published in public media, implying the crisis scale. Citizens living around this area have expressed their strong dissatisfaction with the release of unpleasant odor, which can trigger respiratory diseases as well as other ailments like skin problems.

With regard to the results, another issue deserving attention is that the existence of the Kahrizak landfill has posed a menace to the Imam Khomeini airport. The presence of birds with high density in these areas threatens the course of flights and causes visual pollution. Passengers' complaints about inhaling unpleasant smells in the vicinity of Imam Khomeini airport have been recurrently reported. Local people's satisfaction, which is the fifth priority, overlaps with distance to the city limit as the second priority.

Corrective and controlling actions:

The first survey identified and prioritized risks associated with waste management and environmental issues in Tehran. To find out risk mitigation strategies to address environmental problems, a follow-up survey was conducted. The second survey was distributed among 92 experts in waste management to explore solutions to handle 22 risks caused by the Kahrizak landfill. According to the second survey results, 92% of experts agreed or strongly agreed on nine corrective actions. A detailed discussion of the second survey results is provided in the following.

1. Relocating to a more suitable location: Since this strategy is costly, time-consuming, and requires installing facilities in the new landfill location, this can be a long-term solution and requires making new laws.

2. Increasing waste separation prior to collection: Increasing waste separation prior to collection improves composting and waste incineration efficiency. The most economically and ecologically appropriate method for better waste management in two Iran provinces is recycling and waste separation prior to collection (Vahidi et al., 2017).

Table 5. Identified risks, their causes, effects, and statistical measurements

Risk	Risk Cause	Risk's Potential Effect	Target group	SA[1]	Pr[2]	D[3]	RPN[4]
Land-use change	Building a landfill in the vicinity of residential areas, agricultural lands, and pastures	Reduced prices of surrounding lands, The reluctance in investment and construction in the area	Citizen's satisfaction Local economy	8	5	5	200
Proximity to the city limit	No observation on the proximity of urban settlements during decision about landfill location	Visual pollution Air pollution	Citizens' health Citizen satisfaction Local economy	7	4	4	112
Proximity to the local airport	No observation on maintaining recommended proximity to the airport	Threat to airplane's engine due to birds accumulatio, Hazard to the aircrafts passengers Decrease in the willingness of Visual pollution	Citizen's satisfaction Citizens' safety Local economy	8	4	3	96
High hazard seismic zone	Failure to comply with seismic requirements for the landfill construction near to the fault	Infiltration of leachate into the groundwater	Citizens' health Citizens' safety	8	3	3	72
Economic downfall	Fire in the area Noise pollution Visual pollution Land-use change	lands Reduced prices of surrounding Undeveloped area Evacuation of the area	Citizens' health Local economy	7	2	5	70
Spread of odor to the residential area	Lack of proper coating Improper leachate control Long storage time Transportation through public roads Wind direction Incorrect compost	Birds accumulation Air pollution Evacuation of the area	Citizens' satisfaction Citizens' health Citizens' safety	4	4	4	64
Dust	Improper disposal at the landfill Prevailing wind direction Waste incineration at the landfill Machinery and excavation operations No paved routes	Air pollution Visual pollution	Citizens' health Environmental impacts	4	4	3	48

Risk	Risk Cause	Risk's Potential Effect	Target group	SA[1]	Pr[2]	D[3]	RPN[4]
Occurrence of fire	Waste incineration at the landfill instead of more convenient disposal methods	Emission of odors, Dust, Air pollution, Visual pollution	Citizens' satisfaction Citizens' health	6	2	4	48
Covering material	Failure to use a suitable coating layer, coating with clay layer and the	Emission of odor, Light waste dispersion Infiltration of rain into the waste,	Citizens' health Environmental impacts	6	2	3	36
Groundwater pollution	Infiltration of leachate contaminate the existing high-level groundwater and surrounding wells	pollution (BOD and COD) Soil Disease transmission	Citizens' health Environmental impacts	8	2	2	32
Distance from places protected by the Cultural Heritage Organization	Improper design about landfill location Urban development	Damage to tourist attraction potential Damage to the tourism economy Air pollution, Visual pollution	Citizens' satisfaction Local economy	7	2	2	28
Wind direction	Dispersing smell, dust, and light debris to surrounding residential areas	Visual pollution, Negatively impact airport functionality and protected areas, air pollution	Citizens' health Local economy	6	2	2	24
Distance to bodies of water	Non-observance of the allowed distance to rivers and lakes	Water pollution	Citizens' health Environmental impacts	8	1	3	24
Visual pollution	Non-observance of legal distance to the nearest urban settlements and main road Traffic of garbage trucks from the main routes of citizens, Waste incineration at the landfill, Lack of fence	Reduced prices of surrounding lands	Citizens' satisfaction Local economy	4	2	3	24

Risk	Risk Cause	Risk's Potential Effect	Target group	SA[1]	Pr[2]	D[3]	RPN[4]
Domestic animals' passage	Failure to observe the distance to pastures, No fencing, Feeding livestock with waste,	Disease transmission	Environmental impacts	7	1	3	21
Quality of liner	Inefficient design of a liner layer, Neglecting rainfall amount in design	Leachate infiltration into groundwater	Environmental impacts	7	1	3	21
Rainfall amount	Occurrence of torrential rains in the region that increase leachate production of Lack of coordination of the amount leachate production with the cover layer	Increase leachate, flood, stop burial operations, negatively impact compost process output, create floods, disperse waste	Environmental impacts	6	1	3	18
Dispersal of light waste	Improper cover materials, No fencing Prevailing wind direction and intensity	, Disease transmission Birds accumulation Visual pollution Threat to airplane's engine	Citizens' safety Citizens' health	4	2	2	16
Proximity to preserved area	Failure to observe the minimum distance to the accumulation place of plant and animal species	Visual pollution	Environmental impacts	6	1	2	12
Proximity to hospital centers	Non-observance of distance to hospital centers	Decreased service quality Air pollution Visual pollution	Citizens' health	9	1	1	9
Bird habitat	Failure to observe the distance to the accumulation places of birds Feeding birds with waste	Disease transmission Visual pollution	Environmental impacts	6	1	1	6
noise Pollution	Garbage trucks traffic in main roads, Drilling operations to expand the landfill Improper waste unloading	Mental disease	Citizens' health	5	1	1	5

1: Severity Assessment,
2: Probability of Risk using AHP,
3: Detection,
4: Risk priority number

Also, an increase in waste separation before collection leads to an increase in recycling, which in turn leads to a decrease in the amount of incoming waste to the landfill. A decrease in the number of trucks carrying waste to the landfill can reduce Tehran's municipality's expenses. The money saved this way can be invested elsewhere. Sectors in which the municipality can invest to reduce the risk of identified hazards include compost units and waste incinerators and purchasing fully modern automated waste processing facilities.

3. Equipping compost unit: Kahrizak compost unit has released a foul smell due to its low operation. Equipping this unit will help reduce this unpleasant odor.

4. Sprinkling water in the operational area to reduce dust particles: Garbage trucks' traffic creates dust on paths and the spreading of ash from the incinerator. By sprinkling water in the area, the settled dust can be prevented from rising again.

5. Automating facilities for segregation at destination: Using automated segregation machinery at the destination, like separating metals with magnetism or separating light components by floating, can lessen the incoming waste to the final burial location. Also, with regard to the fact that the population of megacities compared to other places has a higher growth rate due to the concentration of facilities and that the waste production rate in Iran is positive, authorities need to develop landfill sites in the following years. Segregation at source and destination can compensate for the increase in the amount of waste produced in the upcoming years.

6. Using appropriate plant species in the landfill site to reduce dust and eliminate visual pollution: Using plants in other landfills has been significantly efficient in reducing pollution.

7. Developing leachate purifier: Since landfills' leachate has a substantial pollution burden, equipping a landfill with a purifier with the capacity to purify the chemical and biological leachate can reduce this pollution burden at the source, hence lowering concerns regarding penetration of leachate into the groundwater in case of cataclysms like an earthquake.

8. Using proper filters for the incinerator: Not using filters due to issues like economic sanctions and high prices can cause toxic gas and dust to be freed in the area. To reduce the hazards of this risk, corrective actions aiming at supplying proper filters can help.

9. Planting suitable plants for the landfill: Planting outdoor plants not only improves the area aesthetically and separates the landfill from the surrounding areas, but it also can help with the purification process. The purification capacity that the right plants have can reduce the pollution burden. Using plants means less dust would rise up in the air from the prevailing wind while significantly decreasing the nearby area's malodorous smell.

Conclusion

This research studied the management of risks associated with the Kahrizak landfill site, Tehran. A survey conducted among 130 experts to identify and prioritize was management risks. Based on the first survey results, a follow-up survey was conducted among 92 experts to identify solutions to the risks. The first survey results showed Kahrizak landfill imposes 22 risks for citizens’ satisfaction, citizens’ health, citizens’ safety, the environment, and the local economy. The second survey identified nine corrective actions that address waste management risks in Tehran. The study recommends implementing the nine corrective actions to deal with risks with the highest priorities significantly mitigate risks associated with waste management in Kahrizak landfill, with the highest efficiency and the lowest cost. Implementing the recommended actions will diminish the pollution near the landfill, decrease hazardous environmental materials, and improve the residents’ health condition in landfill neighborhood.

Among the 22 risks, this research shows that these three risks had the highest priority. (1) Change in land use: Change in land use in the surrounding districts downgrades property value. If the minimum distance from densely populated areas is not kept, the close distance causes residents'' dissatisfaction due to improper and non-engineered landfill operation. (2) Distance to the city limits signs: If the recommended distance is not kept, the risks threaten citizens' health, noise pollution, visual pollution, and contamination of groundwater used by citizens. (3) Distance to the airport: The number of birds feeding on waste in landfill sites has increased, which poses a serious threat to airplanes regarding the fact that the Kahrizak landfill is in the vicinity of Imam Khomeini airport. Also, the release of unpleasant odor at airport premises has led to passengers' dissatisfaction, resulting in a decrease in passengers' willingness in general and foreign passengers, particularly to fly from this airport, damaging the reputation of Iran's largest airport.

To the best of our knowledge thus far, the present research findings can be regarded as one of the first experiences that have touched upon the Kahrizak landfill site. Therefore, using these findings can enhance waste disposal services and improve citizens' satisfaction with garbage collection and waste disposal operations. It is recommended that for each of the risks identified in this study, along with corrective actions, the risk severity, occurrence probability, and detectability potential can be calculated again, and in the subsequent stage, the effectiveness of each corrective action can be analyzed.

Although we collected a specific group of participants and saved their contact information, it was hard to communicate and receive responses from all of them in the second survey. Another limitation in this study was to access valid data to develop the questionnaire, study the risks, and dig deeper into each risk factor. The identified and prioritized risks can be examined and studied in detail by other researchers to assess the potential risk factors, i.e., probability, severity, and detection rate, and identify how to manage the risks and mitigate RPNs.

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