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Original Article

Environmental risk assessment of dry solid waste separation in urban districts using FMEA: a case study in Karaj city

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Abstract

***Background & Aims*:** The interaction of household waste with many waste materials that are now used in various forms in industries and residential homes, and their lack of separation, has doubled the problems of garbage collection and disposal. This study aimed to assess the environmental risks associated with dry solid waste separation at a designated hall in District 10 of Karaj, Iran, utilizing the Failure Mode and Effects Analysis (FMEA) method.

***Materials & Methods*:** The FMEA method was employed to identify and evaluate potential environmental hazards, including soil and groundwater pollution, air pollution, noise pollution, and reduced fuel resources. Risk Priority Numbers (RPNs) were calculated for each hazard based on severity, occurrence, and detectability.

***Results*:** The results indicated that soil pollution from salon washwater (RPN 504), air pollution from burning dry waste (RPN 441), and groundwater pollution from salon washwater (RPN 448) posed the highest risks. Other significant risks included soil pollution from spraying (RPN 288), groundwater pollution from pesticide spraying (RPN 294), and reduced fuel resources (RPN 280) .

***Conclusion*:** The findings emphasize the need for critical control measures, such as installing a standard septic tank, prohibiting the burning of waste, improving the hall's flooring and drainage system, and implementing proper waste disposal and disinfection practices. This study underscores the importance of a comprehensive risk assessment approach for effective waste management and environmental protection in urban areas.

***Keywords*:** Environmental risks, FMEA, Risk assessment, Waste separation

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Introduction

The Organization for Economic Cooperation and Development (OECD) considers waste to be the result of human activity, which is essential for processing and disposal (1). The daily increase in urban waste production is one of the most important factors threatening the health of the global environment (2). Over time, as progress has been made in the thinking and actions surrounding recycling materials, processing has gradually been added to these devices (3). Every Iranian person produces an average of 700-1000 grams of waste per capita (4, 5).

Urban solid waste composition has changed significantly. These changes have put more pressure on the existing environment, human health and urban waste management (6). Risk assessment is one of the main pillars of health, safety, and environmental management systems, which aims to identify, evaluate, and control risk factors (7). Today, in many countries, the principles of risk assessment and management have been influenced by safety, health, and environmental regulations, as well as many other laws (8).

To minimize environmental degradation and adverse impacts, it is necessary to drive sustainable development in all institutions, organizations, and educational centers using new management systems (9). Preventing injuries and accidents should be prioritized in order to develop sustainably and increase productivity while considering health (10). Environmental risk assessment, which is the process of estimating the likelihood of a desirable or undesirable event and its impact is a step beyond traditional risk assessment (11).

Much waste is valuable and can be reused, becoming a primary source for the production cycle of various industries or energy production (12). The separation of municipal waste at the point of origin is the main link in the recycling chain, and the main factor in implementing this project is attracting the participation and cooperation of the people (13). Studies show that Germany and Sweden have started their work by training and attracting people to cooperate in the field of waste separation from scratch (14, 15).

FMEA is a systematic and preventive risk management tool that identifies and corrects potential problems (13). The goal of this method is to identify potential system risks (14). This method is based on teamwork (15). It is now widely used in a variety of industries (16). FMEA acts as an effective tool to ensure that potential threats to the system and associated risks are minimized (17). This study represents a pioneering effort in assessing the risk management of environmental factors. This study assesses the environmental risk of dry solid waste separation in urban districts using FMEA.

Materials & Methods

Study Area

The dry waste separation station of District 10 is located in the Khalaj Abad area, as shown in Figure 1, where a volume equivalent to 1 ton of dry waste from Districts 1, 2 and 10 of Karaj is brought in daily, and then separated in the separation hall with an area of 500 m^2. The hall has a staff rest room, sanitation services, and a separation hall, and is managed by the contractor of the contracting party with the Waste Management Organization of the municipality of Karaj (18).

Failure Mode and its Impact Analysis (FMEA)

Among the risk assessment methods, some of the most commonly used include Preliminary Risk Analysis, (19) Failure Mode and Effect Analysis (FMEA), Hazard and Operability (HAZOP), Fault Tree Analysis (FTA), and Event Tree Analysi (23-24).

FMEA is one of the most important methods in Systems Safety Engineering, developed based on reliability engineering. This method can be used to identify a variety of potential failures and propose corrective actions to improve the reliability and safety of systems, processes, and products (20).

The FMEA method is used to analyze the data, which is an analytical method based on the principle of "pre-occurrence prevention" that aims to predict existing problems, defects and risks. Preventing failure in projects through integrated risk analysis can be considered as the objectives of this method (21).

Environmental Risk Assessment

Initially, information was collected through interviews with experts and workers at the District 10 Separation Hall located at the Khalaj Abad transfer station in Karaj. The guidelines contained in the field visits were then studied and reviewed in terms of compliance with these guidelines. Dry waste is collected by the contractor's manpower from the city level and transported by car to the separation hall, where it is processed according to Figure 1.

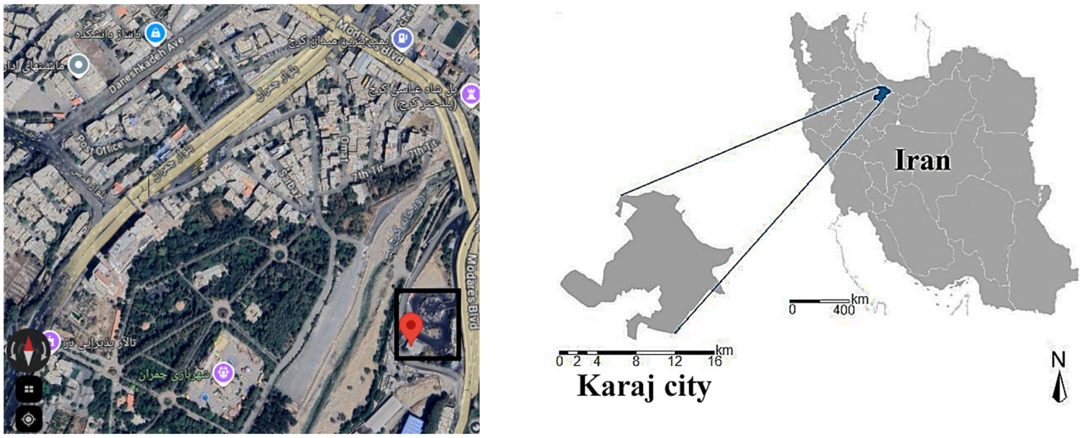

Fig. 1. Dry waste separation station

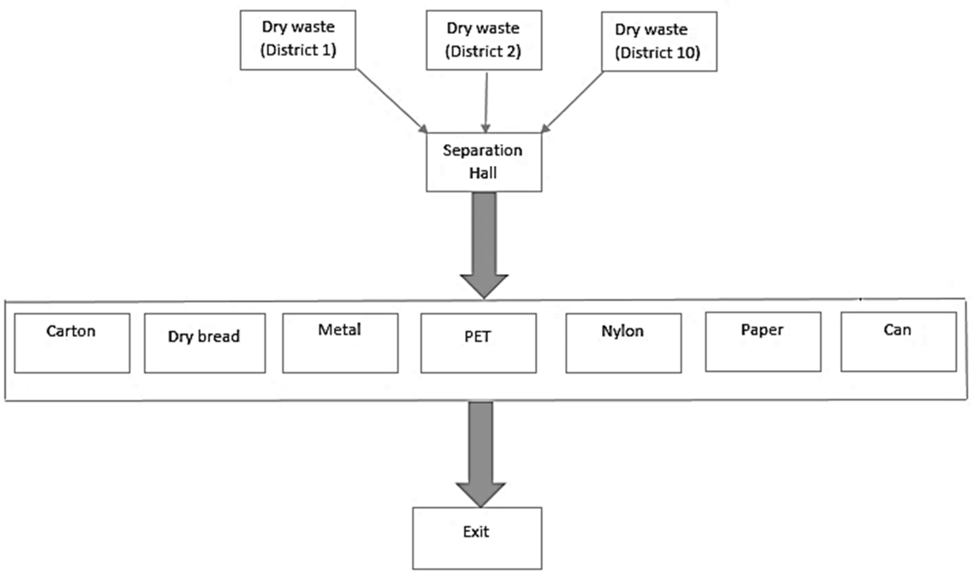

Fig. 2. The process of working in District 10 separation Hall

Using methods such as checklists, documentation reviews, surveys of operators related to different sectors, and walking-talking through, a basic list of the most important risks in the environmental sphere was developed (27). The risk index in the FMEA method includes the risk priority number, determined using three parameters: severity is the probability of occurrence and detection. The product of these three parameters determines the Risk Priority Number (RPN) number (28, 29).

$$RPN = O * S * D$$

RPN: risk priority number, O: probability of occurrence, S: severity of effect, D: detectability

To determine the severity of the effect, we used Table 1 and assigned values from one to 10 based on the impact of the risk involved.

Table 1. S (severity) index of failure

Order (S)	Criterion severity	Impact
$9 \leq S \leq 10$	Causing fatalities or complete system breakdown	Lethal
$8 \leq S \leq 7$	Inflicts severe harm to individuals or has a substantial impact on the system	More detrimental
$6 \leq S \leq 5$	Results in lesser harm or a reduced impact on the system. Less	Less detrimental
$4 \leq S \leq 3$	Signifies a significant impact on individuals or the system with complete recovery.	Moderate
$S = 2$	Causes minimal disruption to the system or individuals	Low
$S = 1$	No effect on people or the system	No effects

To determine the probability of occurrence using Table 2, we selected a value from the inevitable probability (numerical value of one) to the impossible probability (numerical value of 10) for each risk.

Table 2. (O - Occurrence) index of failure

Order (O)	Criterion: the proportion of potential failure/total number of working days.	Likelihood of failure
10	$O \leq 1: 2$	Extremely high
9	$O \leq 1: 10$	Extremely high
8	$O \leq 1: 20$	High
7	$O \leq 1: 100$	High
6	$O \leq 1: 200$	Moderate
5	$O \leq 1: 1000$	Moderate
4	$O \leq 1: 2000$	Somewhat minimal
3	$O \leq 1: 10000$	Extremely low
2	$O \leq 1: 20000$	low
1	$O \leq 1: 50000$	Infrequent

We assigned a number to the discovery capability according to Table 3, ranging from Number one, representing inevitable discovery capability (i.e., it continues to be revealed despite controls), to Number 10, indicating a situation where there is absolutely no risk without control, and even with control applied, the risk is not revealed.

Table 3. Rating for the capability to detect failures (detection)

Order (D)	Identifiable percentage	ID
10	Completely unknown	$0 \leq D \leq 5$
9	Very detailed	$6 \leq D \leq 15$
8	Partial	$16 \leq D \leq 25$

Order (D)	Identifiable percentage	ID
7	Very little	$26 \leq D \leq 35$
6	Low	$36 \leq D \leq 45$
5	Moderate	$46 \leq D \leq 55$
4	Moderately high	$56 \leq D \leq 65$
3	High	$66 \leq D \leq 75$
2	Too high	$76 \leq D \leq 85$
1	Almost known	$86 \leq D \leq 100$

After the RPN number for each risk is obtained, the risk class and the measures required for it can be determined using Table 4. The RPN number is categorized into four classes as follows: RPN < 70 is considered low risk, 70 ≤ RPN < 200 is categorized as moderate risk 200 ≤ RPN < 400 indicates high risk, and RPN > 400 signifies extremely high risk.

Table 4. Risk leveling

RPN number	Risk class
RPN < 70	Low
70 ≤ RPN < 200	Moderate
200 ≤ RPN < 400	High risk
RPN > 400	Extremely high risk

Results

Nine environmental hazards were identified: 1-Reduced fuel resources caused by the activity of carriers, 2-Air pollution from burning dry waste, 3-Noise pollution from cars, 4-Soil pollution from salon washing, 5-Groundwater pollution from salon washing, 6-Soil pollution from lime spraying, 7-Groundwater pollution from Lime spraying 8-Soil pollution from spraying, 9-Groundwater pollution caused by pesticide spraying. These hazards, related to the Khalaj Abad waste separation hall located in District 10, were identified and recorded in the worksheet according to Table 5. For each hazard, the probability of occurrence, the severity of the effect, and detectability were determined.

Table 5. Filled out risk calculation

No.	Risks	O	S	D	RPN	Risk class
1	Reduced fuel resources caused by activity of carriers	8	7	5	280	High risk
2	Air pollution from burning dry waste	8	9	7	441	Extremely high risk
3	Noise pollution from cars	5	5	6	150	Moderate
4	Soil pollution from the salon wash	7	8	6	504	Extremely high risk
5	Groundwater pollution from the salon wash	8	7	8	448	Extremely high risk
6	Soil pollution from Lime spraying	5	7	5	175	Moderate
7	Groundwater pollution from Lime spraying	5	7	5	175	Moderate
8	Soil pollution from spraying	6	8	6	288	High risk
9	Groundwater pollution caused by pesticide spraying	7	7	6	294	High risk

The results of the environmental risk assessment of the separation hall showed that soil pollution from the salon wash with a value of 504 RPN air pollution caused by burning dry waste with a value of 441 RPN, and groundwater pollution caused by washing the hall, with a value of 448 RPN, were the highest environmental risks. Following these, soil pollution caused by washing the hall, groundwater pollution caused by spraying, soil pollution caused by spraying, and reduced fuel resources caused by the activity of carrying vehicles, with RPN values of 336, 294, 288, and 280, respectively, were categorized as high-risk. Soil pollution from lime spraying and groundwater pollution from lime spraying, with an average risk level of RPN 175, were next. The most and least RPNs are visible in Table 1.

Discussion

Environmental risks associated with the activities and services of Amir Kabir Industrial University were identified and evaluated by combining two Delphic methods and the semi-quantitative FMEA method. According to the results of the risk assessment, natural disasters such as lightning, surface water pollution, and solid waste caused by earthquakes and floods, air pollution caused by gas pipeline leaks or fires during earthquakes; explosions caused by plant processes, groundwater pollution resulting from the production and disposal of sanitary and laboratory wastewater, destruction of natural resources, and the production of special waste were classified as high risks. Based on the comparison of risk levels, 44% of risks were high, 48% moderate, and 8% low (9). The spread of various diseases, including hydatid cysts, plague, various skin diseases such as leishmaniasis, and chronic cancer diseases, is associated with urban waste and its spread in water, soil, and, air (22).

The factors influencing waste separation from the source include seasons of the year, economic conditions, and literacy levels of the population. Separation from the source is carried out with objectives such as recycling waste and returning it to the production and recycling cycle, reducing the cost of collecting and burying waste, saving the land needed for waste burial, reducing the cost of repairing and maintaining compost factories, and producing more desirable compost (23).

In the civil and environmental study of the risk assessment of environmental aspects of crude oil reservoir construction in Qeshm, a similar method was applied. Eleven important activities were identified, among which the poor engineering of equipment and current methods in refueling equipment gave it an environmental risk priority number of 120. The use of absorbent wells at the beginning of the project and the resulting soil pollution from human sewage caused this aspect to have the most negative environmental impact, with a score of 560 (24).

Estimates of the risk level of landfills for adjacent areas revealed that 40% of the total number of landfills were located in the pre-crisis condition area, 53% were in the crisis zone, and 7% were in the critical area (25). Njoku et al. studied the health and environmental risks of residents living near the landfill in South Africa's Limpopo province. The results of the study showed that 78%of participants living closer to the landfill experienced serious air quality pollution, evidenced by the foul odor associated with the landfill (34).

Rostamkolaei et al. conducted a study using the WILLIAM FINE method to assess the environmental risks of the compost plant in Behshahr. The results indicated that the highest risk with a risk number of 388, was related to sewage and rejects, which caused soil, surface water, and groundwater pollution. The results of the study showed that the plant had risks exceeding high-risk levels (26).

Pahanandeh et al. evaluated the environmental impact of the Yazd compost plant based on a study of the main long-term effects of the project during the operational stage. These included sewage and its possible penetration into groundwater, health risks inside the plant for workers, and risks to the external environment (mainly from insects and pests), as well as olfactory pollution and crop contamination. Corrective action was strongly recommended (27).

In a study on environmental risk assessment in one of the exploitation plants of the national oil regions of the South, Mas et al. applied the William Fine method. Based on the results of this study, the highest percentage of pollution in the exploitation unit was for water (45.20%), soil (72.29%), air (72.47%), and noise (28.2%). The lowest level of pollution was noise, while the highest was air pollution (28).

Source reduction and recycling are the two most desirable operations to achieve waste minimization, which has therefore encouraged the collection of recyclable materials at the source for a long time in China. This approach will be useful in minimizing the total waste for the transport and treatment stages (29). In their study Sadeghi et al. concluded that preventive measures in waste management have the highest efficiency, the highest priority, and the lowest cost (30, 31).

In a study with a similar methodology in Tehran, it was demonstrated that the Failure Mode and Effects Analysis (FMEA) approach was utilized to manage medical waste, accurately identifying key risks. For instance, it was determined that the risk associated with improper cleaning of waste containers had a RPN exceeding 150, marking it as one of the highest dangers. Furthermore, other risks such as improper waste accumulation and poor management of infectious materials were identified with RPN values between 80 and 120. This information highlights the critical need to address these issues explicitly and take steps toward improving systems and training personnel. The overall results indicated that by employing this tool, effective changes could be made to reduce the risks associated with medical waste management (32).

The processes of medical waste management were examined along with the assessment of risks associated with them using FMEA. A total of 33 potential risks were identified with RPN ranging from 30 to 360. The highest RPN was linked to inadequate cleaning of waste containers, while the lowest pertained to the absence of safety boxes for sharp waste. The use of the FMEA method contributed to the identification and prioritization of risks, enabling improvements in the processes of medical waste management. Effective handling of medical waste, not only minimizes risks but also aids in safeguarding public health and the environment (33).

According to Figure 3, 34% of the risks (soil pollution from salon wash, groundwater pollution from salon wash, air pollution from burning dry waste) are categorized as extremely high risk at the RPN level. Additionally, 33% fall under the high-risk level (reduced fuel resources caused by carriers of activity, soil pollution from spraying, groundwater pollution caused by pesticide spraying), while the remaining 33% are at the moderate risk level (noise pollution from cars, soil pollution from lime spraying, groundwater pollution from lime spraying).

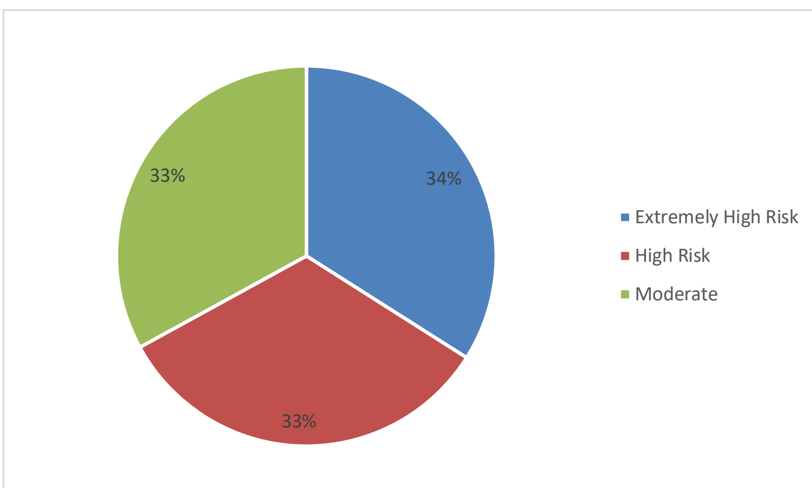

Fig. 3. Abundance of different levels of risk

For proper waste management in the United States, waste processing and disposal laws in Japan, and national waste policies in Australia, among others, are some of the strictest regulations in this regard. They all emphasize the prevention of waste production, processing for recycling and reuse, converting waste into energy (biogas and electricity), and the sanitary burial of waste (34).

Conclusion

According to the results, it is concluded that in the Khalaj Abad waste separation hall, there are environmental risks with an extremely high risk level (soil pollution from the salon wash, groundwater pollution from the salon wash, air pollution from burning dry waste) and high-risk levels (reduced fuel resources caused by activity of carriers, soil pollution from spraying, groundwater pollution caused by pesticide spraying), which make it necessary to carry out control measures. The station should be equipped with a standard septic tank, the burning of wooden and bulky waste should be prohibited, and the hall should be equipped with a rest-room containing cooling and heating equipment. Additionally, the floor of the hall should be improved to ensure it is smooth and impenetrable. The salt floor should be installed with standard plumbing that directs wastewater to the septic tank. This will ensure that washed and sprayed lime, as well as spraying and disinfecting consumables, do not enter the soil and are safely directed to the septic tank, greatly reducing the risk of contamination This will, in turn, help reduce water and soil pollution in the area.

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Author’s Contributions

Fariba Jalali and Nahid Ghobadi designed and conducted the study, carried out the field process, and drafted the original paper. All authors reviewed the final manuscript.

Data Availability

The data supporting these findings are available from the corresponding author upon reasonable request.

Conflict of Interest

The authors have no conflict of interest in this study.

Ethical Statement

Informed consent was obtained from all adult human participants.

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