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Risk Assessment of Urban Waste Management through EFMEA and TOPSIS Methods (Case Study: District 6 of Tehran Municipality, Iran)

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A B S T R A C T

Background: We assessed and ranked environmental risks in the mechanized urban waste collection and storage systems in Tehran municipality (Iran) to locate safe areas for the establishment of these systems.
Methods: This descriptive-analytical study first identified and classified the effective factors in locating the mechanized systems of the studied district in seven criteria (socioeconomic, physical-spatial, hydrological-climatic, geological, and three passive defenses including dispersion, lifeline, and high-risk facilities). Risk factors were evaluated using the FMEA technique and prioritized using the TOPSIS method.
Results: The FMEA results classified the identified passive defense and environmental risks into three levels (high, medium, low), with 69% of the risks at the low level, 17% at the medium level, and 14% at the high level. The TOPSIS ranking results identified "Distance to nearest fire station", "Distance to a fault" and "Distance to power substation" as the highest risk factors with the similarity to ideal solution (cl_i)values of 0.861, 0.774 and 0.771, respectively, as well as "Distance to gas pressure-reducing stations" (cl_i = 0.134) as the least important risk factor.
Conclusion: New urban waste collection and storage stations in the studied district should be established according to the population of the areas and at a suitable distance to the nearest fire stations. Further, locating and designing these systems in wide open spaces is highly essential.

1. Introduction

Waste generation is increasing as consumerism grows worldwide. The tolerance capacity of both natural and man-made systems is threatened by the dynamics of consumerism, the expansion of capitalism, and urbanization; therefore; it is estimated that there will be about 9 billion people in 2050, 80% of whom will live in cities. By 2025, the world is expected to see a fivefold increase in waste generation alone [1,2,3]. According to the World Health Organization (WHO), solid waste disposal is one of the most serious problems caused by urban and industrial development [4,5]. One of the tasks of urban management is crisis management, which includes measures before the crisis, at the beginning of the crisis, during the crisis, and after the crisis. Scientific findings confirm the vital role of municipalities as government organizations in crisis management [6]. Identifying and characterizing different types of crises helps planners, decision-makers, and managers deal with them by adopting appropriate strategies [7,8]. Crisis threats in urban waste management do not disappear completely, however they can be reduced to an

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acceptable level by considering passive defenses [2]. Exploring the risk factors, and identifying the risk type and possible risks at the time of accidents are the most key measures to reduce vulnerability through the passive defense approach. Therefore, there is a need to formulate comprehensive indicators and a strong risk analysis technique to achieve effective management scenarios to prevent or reduce vulnerability and consequences [9,10]. Risk assessment is a process that benefits from the results of risk analysis by ranking and comparing them with target values (functional goals with legal requirements) for decision-making [11]. Environmental risk assessment is a step beyond risk assessment, which not only examines and analyzes various aspects of risk while fully understanding the environment of the affected area but also considers the degree of susceptibility of the affected environment as well as the specific environmental values of the region in the risk analysis and assessment of the region [12,13]. There are various methods to assess environmental risks, including failure modes and effects analysis (FMEA), Hazan, and Fine William, each of which has its advantages and disadvantages depending on the study area [14,15]. Like all risk assessment methods, FMEA can identify and assess the risks. According to various applications, there are different FMEA techniques, including FMEA related to the environment, i.e. the Environmental Failure Modes and Effects Analysis (EFMEA) [16]. A review of the history of the use of multi-criteria decision-making (MCDM) methods in risk assessment reveals that such techniques have been employed alone or in combination with other approaches for risk assessment in different cases [17]. Niavrani (2004) [16] investigated the application of the FMEA technique in identifying and evaluating environmental aspects and introducing the EFMEA method. Nikandish (2019) [18] used AHP and TOPSIS methods to identify and analyze environmental risks in the conservation area. Jozi et al (2010) [19] used TOPSIS and AHP methods in the analysis of the physical risks of Balaroud Dam in Khuzestan during the construction phase. Vinodh et al. (2014) integrated fuzzy AHP and TOPSIS methods for selecting the best plastic recycling method [20]. Farrokhian et al. (2012) [21] assessed the environmental, health, and safety risks in Hakim Farabi Agro-industry Company (Iran) using the integrated TOPSIS-FMEA model and prioritized the identified risks in three distinct, tolerable, and non-distinct levels. Makvandi et al. (2012) [22] analyzed the environmental risk of Shirinsoo wetland in Hamadan province (Iran) using TOPSIS and EFMEA techniques and determined the significance coefficient of the identified risks and accordingly presented management priorities for the risk control. Habibi et al. (2013) [23] used TOPSIS and FMEA models to prioritize safety risks in the operation process of Mazandaran Regional Electric Company (Iran) and identified seven high risks to control the operations. Early identification of risk factors using the FMEA technique and their ranking with the TOPSIS technique can make it easier for managers to make decisions about urban waste management in critical times in the region. Therefore, the present research was conducted to identify, classify, and evaluate the resulting environmental risks for the proper management of urban waste collection and storage systems in district 6 of Tehran Municipality, Iran.

2. Materials and Methods

The present descriptive-analytical research was carried out by using MCDM and FMEA methods. First, effective factors in the location of mechanized urban waste collection and storage systems in district 6 of Tehran municipality were identified (Figure 1) in the form of seven criteria (socioeconomic, physical-spatial, hydrological-climatic, geological, and three passive defenses including dispersion, lifeline, and high-risk facilities), and 35 sub-criteria. Then, the threats and damages of urban wastes during the crisis were ranked by the reliable and applicable TOPSIS method due to its high sensitivity to the weight of each factor [24-27]. The maximum group of experts related to the environment and waste management organization was used to reduce the error rate.

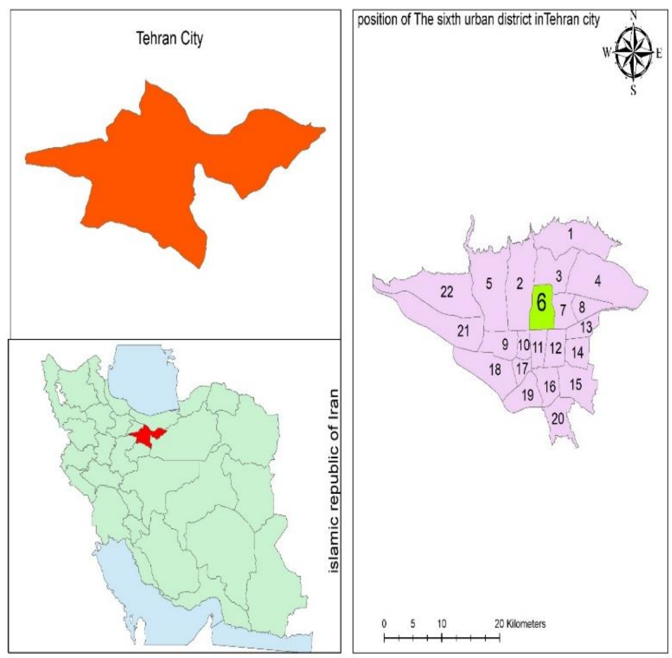

Figure 1: Geographical location of District 6 of Tehran Municipality, Iran

The required field information was collected through interviews with municipal experts of the studied district, and the distribution of questionnaires among the statistical population. The validity and reliability of the questionnaire were determined by Cronbach's alpha coefficient.

2.1 Failure modes and effects analysis (FMEA)

FMEA is an analytical technique based on the law of prevention before the occurrence, which is used to identify potential failure factors. It is also a tool that can be used with minimal risk to predict problems and defects in the design or development stages of organizational processes and services. This technique is designed so that an action can be identified before an incident occurs, rather than after problems become apparent. Therefore, whenever fundamental changes are to be made in the service provision, they should be updated [28]. In this method, the following equation is used to determine the degree of risk of a criterion:

Degree of risk = Range of probability × Severity of effect × Significance of risk

Degree of risk: the probability of a risk becoming a reality

Range of probability: environmental consequences indicating the probability of the occurrence of the consequence in a certain time.

The severity of effect: indicating the extent and scope of damages and losses that will happen in the event of environmental consequences.

Significance of risk: final weight (W_i)

Each risk is graded on a scale of 1 to 10, with 1 being the least risk and 10 being the most severe. The probability of occurrence determines how often the cause or mechanism of a potential risk occurs, which is ranked by assigning a number between 1 and 10 (Table 1).

2.2 Calculation of risk priority number

The risk priority number (RPN) is an indicator to distinguish the acceptable and unacceptable system risks [29]. After calculating the severity, probability, and significance of the risk, the numerical value of the risk is calculated using the following equation:

$$RPN = S \times O \times W_i$$

Where, Wi stands for the score calculated for the significance of environmental risk, (S) for the severity of effect, and (O) for the probability of occurrence. The risk levels determined according to the degree of risk are presented in Table 2.

2.3 Ranking of risk factors by the TOPSIS method

The TOPSIS method, first introduced by Hwang and Yoon in 1981, is one of the multi-criteria decision-making methods. This approach can be used to rank and compare different items, choose the best item, determine the distances between items and group them [30]. In the TOPSIS method, *m* items are evaluated by *n* indicators. Accordingly, the items are selected based on the minimum distance to the ideal solution (the positive ideal solution or the best possible case A_i^+) and the maximum distance to the ideal solution (the negative ideal solution or the worst possible case). It is assumed that the desirability of each indicator increases or decreases uniformly. Solving the problem using the TOPSIS method consists of eight steps [31,32,33]:

Step (1) - Formation of data matrix based on *m* items and *n* indicators or criteria

Step (2) - Standardization of data and formation of the normal matrix

Step (3) - Determining the weight of each indicator (W_i) based on relationships, and forming a weighted diagonal matrix ($_{n\times n}$); in this regard, the more important the indicator is, the more weight it will have.

Step (4) - Formation of the weighted scaleless matrix: by multiplying the weights of the criteria in the scaleless matrix, the weighted scaleless matrix is obtained. In this research, the weights of the criteria were considered to be the same; therefore, the weighted scaleless matrix was equal to the weighted matrix and there was no need to calculate this matrix.

Step (5) - Calculation of the positive and negative ideal solutions

Step (6) - Calculation of the distance of the *i^th^* item based on the Euclidean norm to the positive and negative ideal solutions

Step (7) - Determining the relative similarity coefficient of the *i^th^* item (cl_i) to the ideal solution, where (d_i^-) is the negative ideal solution and (d_i^+) is the positive ideal solution. The cl_i indicates the similarity to the positive ideal solution and the distance from the negative ideal solution.

Step (8) - Ranking the items based on the value of cl_i, which fluctuates between 0 and 1, where cl_i=1 indicates the highest rank and cl_i=0 indicates the lowest rank.

$$A^+ = \{(\mathrm{Max}\ vij|j^+),(\mathrm{min}vij\ |j^-)\} \longrightarrow$$

$$V_{ij} = R_{ij} * W_{n*n}$$

$$\sum_{i=1}^{n} W_i = 1$$

$$R_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a^2{}_{ij}}}$$

$$A^- = \{(\mathrm{Min}_{i=1}^{m}\ vij|j^+),(\mathrm{max}\ vij\ |j^-)\} \longrightarrow$$

$$\sum_{i=1}^{n} W_i = 1$$

$$d_i^+ = \left\{\sum_{j=1}^{n}\left(V_{ij} - V_j^+\right)^2\right\}^{1/2} ;\ (i = 1,2,\ldots,m)$$

$$Cl_i{}^- = d_i^+ \big/ d_i^- + d_i^+ \quad \text{or} \quad Cl_i{}^+ = d_i^- \big/ d_i^- + d_i^+$$

$$d_i^- = \left\{\sum_{j=1}^{n}\left(V_{ij} - V_j^-\right)^2\right\}^{1/2} ;\ (i = 1,2,\ldots,m)$$

Table 1: Ranking of the probability of occurrence and severity of risk

Rank	Probability of risk occurrence	Probable rates of risk	The severity of the risk effect	Description
1	Unlikely: unlikely risk	1 per 1,500,000	None	No effect
2	Very low: Relatively rare risks	1 per 15,000	Very minor	It has a very minor effect on the system's efficiency.
3	Low	1 per 15,000	Minor	It has a minor effect on the system's efficiency.
4	Relatively low	1 per 2,000	Very low	The effect on the system's efficiency and performance is very low - the system does not need to be monitored.
5	Medium	1 per 400	Low	The effect on the system's efficiency and performance is low - the system needs monitoring.
6	Relatively high	1 per 80	Medium	The effect on the system's efficiency is moderate, system performance is degraded - functions may not work normally.
7	High	1 per 20	High	There is a lot of deterioration. The effect on system efficiency is high. System performance is severely affected but it works. The system may not work properly.
8	Recurrent risks	1 per 8	Very high	Deterioration is irreversible and occurs without warning. The effect on the system's efficiency is very high. The system will be unusable.
9	Very high	1 per 3	Hazardous with warning	Degradation is unfortunate, but comes with a warning - it does not comply with environmental regulations or standards.
10	Ultra - high: almost inevitable	2 or more	Hazardous without warning	Deterioration is unfortunate and occurs without warning. It stops the system's performance. It does not comply with environmental regulations.

Table 2: Degree and level of passive defense, environmental and health risks in the waste management system

degree of risks	Level of risks	Description
0-10	Low (L)	Acceptable and normal
11-20	Medium (M)	Abnormal conditions
≥21	High (H)	Impossible for emergency reasons

3. Results and Discussion

Based on the probability of risk occurrence in district 6 of Tehran Municipality, 7 criteria with 35 sub-criteria were identified as the most important risk factors of passive defense and environmental indicators (Table 3). Table 4 presents the results of the FMEA method in the location of urban waste collection and storage systems in district 6 of Tehran Municipality. Based on the results of the FMEA technique, the most important effective criteria in locating the municipal waste collection and storage systems in district 6 of Tehran Municipality were classified into three levels: high risk (H), medium risk (M), and low risk (L). Concerning the criteria and the severity of their risk effect, the sub-criterion of "Population density" (RPN = 37.2) in the socioeconomic criterion, the sub-criterion of "Distance to power substation (lifeline)" (RPN = 31.3) in the passive defense (high-risk facilities) criterion, the sub-criterion of "Distance to a fault" (RPN = 28.8) in geological criterion, the sub-criterion of "Proximity to high traffic roads" (RPN = 25.2) in physical-spatial criterion, the sub-criterion of "well depth" (RPN = 22.7) in hydrology and climate criterion accounted for the highest significance of risk in their levels in the mechanized urban waste collection and storage systems in district 6 of Tehran Municipality, respectively. The sub-criterion of "Wind direction" in the hydrological-climatic criterion (RPN = 19.8), the sub-criterion of "Distance to lines of communication" (RPN = 15.8) in the socioeconomic criterion, the sub-criterion of "Distance to sensitive military places" (RPN = 13.9) in the physical-spatial criterion, the sub-criterion of "Distance to the nearest fire station" (RPN = 11.4) in the physical-spatial criterion, the sub-criterion of "Distance to overhead power lines" (RPN = 11.4) in the passive defense (high-risk facilities) criterion and the sub-criterion of "Land use" (RPN=10.3) in the physical-spatial criterion accounted for the most medium criteria in locating, with the medium risk level respectively. The sub-criterion of "Distance to the next trash can" (RPN = 9.8) in the physical-spatial criterion, the sub-criterion of "Distance to watercourses and canals" (RPN = 8.5) in the hydrological-climatic criterion, the sub-criterion of "Worn out texture" (RPN = 8.8) in the physical-spatial criterion, the sub-criterion of "Bedrock type" (RPN = 7.3) in the geological criterion, the sub-criterion of "Distance to facilities and infrastructure network (water supply network, power lines, sewage network, telecommunications, etc.)" (RPN = 6.7) in the physical-spatial criterion, the sub-criterion of "Distance to health centers" (RPN = 6.2) in the physical-spatial criterion, the sub-criterion of "Distance to historical and religious places and monuments in the region" (RPN = 4.3) in the physical-spatial criterion, the sub-criterion of "Density of parks and green spaces" (RPN = 3.5) in the physical-spatial criterion, the sub-criterion of "Depth of aqueduct" (RPN = 3.1) in the hydrological-climatic criterion, the sub-criterion of "Distance to sensitive areas with special ecosystems" (RPN = 2.9) in the physical-spatial criterion, the sub-criterion of "Soil type" (RPN = 2.4) in the geological criterion, the sub-criterion of "Slope" (RPN = 2.4) in the geological criterion, and the sub-criterion of "Distance to water and wastewater treatment plant" (RPN = 1.6) in the hydrological-climatic criterion accounted for the lowest level of risk, respectively.

3.1 Risk ranking by TOPSIS method

After identifying the effective criteria in the location of waste collection and storage systems in the studied district, the next step was to prioritize the most important criteria using the TOPSIS method. Thus, the relative distance of each item to the ideal solution was calculated and sorted from large to small. In this case, the item with the largest relative distance, compared to other items, gets the highest rank or priority. In the TOPSIS method, the nature of the criteria must be determined first, and in our case, the nature of all criteria was positive. In addition, the weights and scores of each criterion were prepared according to the opinions of experts and based on the conditions of the studied district (Table 5). To equalize the values of the normalized matrix, the weights of the desired risk scales should be calculated according to the equations stated in the TOPSIS technique (steps 2 and 3). Since the weights of the criteria in this study were considered the same based on the experts' opinions, the weighted scaleless matrix (R_i) was equal to the weighted normalized matrix (V_{ij}); therefore, there was no need to calculate the matrix (V_{ij}) and display it in the table. The values of positive (A^+) and negative (A^-) ideal solutions for each risk, as well as the Euclidean distance of the effective criteria, were determined respectively through the equations expressed in the TOPSIS technique (steps 5 and 6). Further, the relative similarity coefficients of passive defense and environmental risks were determined by the aforementioned equation (step 7). Finally, the risks were ranked based on the TOPSIS method (Table 6). Environmental risk assessment of urban waste collection and storage system located in district 6 of Tehran Municipality using TOPSIS showed the factors A_1 (Population density, the higher the density; the greater the humanitarian crisis), A_{20} (Distance to a fault; the greater the distance, the less the humanitarian crisis) and A_{24} (Distance to power substation; the greater the distance, the less the humanitarian crisis), as the highest risk factors with similarity to ideal solution (cl_i) values of 0.861, 0.774 and 0.771, respectively. On the other hand, factor A_{34} (distance to gas pressure-reducing stations) was determined as the least important risk factor (cl_i = 0.134).

Table 3: Effective criteria in locating mechanized urban waste collection and storage systems in District 6 of Tehran Municipality, Iran

Criteria	Sub-criteria	Environmental risks (results/effects)
Socioeconomic	1- Population density	Uncontrolled construction debris limits access for servicing, recovery, and reconstruction in the area during a crisis.
	2- Distance to lines of communication	In times of crisis, lines of communication are among the important and key facilities of the city, which facilitate the process of assisting citizens.
Physical-spatial	3- Worn out texture	Worn-out textures are more at risk in times of crisis. The proximity of the waste collection system increases the possibility of environmental risks.
	4- Land use	Uncontrolled disposal of hazardous substances in disposal sites causes potential risks to human health in different uses.
	5- Proximity to high-traffic roads	High-traffic roads are vulnerable during a crisis. The existence of urban waste collection and storage centers near such passages is highly risky.
	6- Density of parks and green spaces	Municipal parks and green spaces as wide open spaces have a preventive role in times of crisis, meaning that these spaces reduce the effects and consequences of risks.
	7- Distance to health centers	Serious health risks to local populations, including outbreaks of disease and infection
	8- Distance to the nearest fire station	The risk of fire during a crisis - the proximity to the fire station plays an essential role in assisting.
	9- Distance to the next trash can	Distances between municipal trash cans in neighborhoods are one of the location criteria for the waste collection system. In times of crisis, if the number of trash cans is large, the crisis will be more severe.
	10- Distance to sensitive military places	Proximity to military and law enforcement centers is associated with short-term and long-term conflicts, which can include missiles, rockets, and bombs, which, along with ground war, lead to damage to buildings and infrastructure, the bombing of key strategic facilities, or extensive damage to industrial and residential areas.
	11- Distance to facilities and infrastructure network (water supply network, power lines, sewage network, telecommunications, etc.)	
	12- Distance to historical and religious places and monuments in the region	Destruction of valuable places by turning them into dumping sites as a result of moving the dumped wastes during the crisis
	13- Distance to sensitive areas with special ecosystems	Destruction of valuable lands by turning them into dumping sites, additional costs due to the transfer of dumped waste

Hydrological-climatic	14- Distance to watercourses and canals	In times of crisis, floods cause mass displacement of household waste, which in turn creates large volumes of household waste. On the other hand, wastes are mixed, and many hazardous substances are mixed with household cleaning products and electronic goods. In addition, flooding may bring mud, clay, and sand to the affected areas, making it difficult to access and disrupting services and assistance in the area.
	15- Wind direction	In times of crisis, the wind causes the smell and pollutants of urban waste to disperse more.
	16- Depth of aqueduct	In times of crisis, waste and its leachate seep into the surrounding aqueducts, causing contamination of groundwater sources.
	17- Well depth	In times of crisis, waste and its leachate seep into nearby wells and cause contamination of groundwater sources and affect the supply of safe drinking water.
	18- Distance to water facilities and tanks	In times of crisis, waste and its leachate seep into water facilities and tanks around urban waste collection and storage centers, cause pollution of urban water resources and affect the supply of safe drinking water.
	19- Distance to water and wastewater treatment plant	In times of crisis, waste and its leachate seep into wastewater treatment plants around urban waste collection and storage centers, cause the pollution caused by the destruction of treatment plants and the spread of pollution in the city.
Geological	20- Distance to fault	The construction of urban waste collection and storage systems in the vicinity of faults during crises such as earthquakes destroys the equipment of these centers and the spread of pollution in the city.
	21- Soil type	The type of soil is important in times of crisis because it affects the infiltration and spread of waste, leachate, and pollutants.
	22- Slope	A high slope can lead to the risk of the rapid collapse of buildings, landslides, and environmental pollution with urban waste.
	23- Bedrock type	The type of bedrock plays an essential role in crises such as earthquakes, landslides, floods, and building collapse. Such crises cause the displacement of huge amounts of waste in the city.
Passive defense (high-risk facilities)	24- Distance to the power substation	The construction of urban waste collection and storage systems in the vicinity of the power substation during crises such as earthquakes destroys the equipment of these centers and the spread of pollution in the city.
	25- Distance to overhead power lines	The construction of urban waste collection and storage systems in the vicinity of overhead power lines during crises such as earthquakes destroys the equipment of these centers and the spread of pollution in the city.
	26- Distance to gas installations	The construction of urban waste collection and storage systems in the vicinity of gas installations during crises such as earthquakes destroys the equipment of these centers and the spread of pollution in the city.
	27- Distance to oil and diesel tank stations	The construction of urban waste collection and storage systems in the vicinity of oil and diesel tank stations during crises such as earthquakes destroys the equipment of these centers and the spread of pollution in the city.
	28- Distance to the gas station	The construction of urban waste collection and storage systems in the vicinity of gas stations and gas pumps during crises such as earthquakes destroys the equipment of these centers and the spread of pollution in the city.
	29- Distance to oil tanks and warehouses	The construction of urban waste collection and storage systems in the vicinity of faults during crises such as earthquakes destroys the equipment of these centers, the mixing of oil products and waste, and the spread of pollution in the city.
Passive defense (lifeline)	30- Distance to the subway	The construction of urban waste collection and storage systems in the vicinity of subway stations during crises such as earthquakes destroys the equipment of these centers and the spread of pollution in the city. The construction of urban waste collection and storage systems in the vicinity of urban facilities and infrastructure networks in times of crises such as earthquakes destroys the equipment of these centers, the interruption of vital city facilities, etc. in the city.
	31- Distance to telecommunications	The construction of urban waste collection and storage systems in the vicinity of communication and telecommunication facilities during crises such as earthquakes causes the destruction of the equipment of these centers, and a lack of access and communication between citizens and aid officials.
	32- Distance to administrative centers	Inability to provide municipal services in times of crisis, such as non-collection of waste, excessive disposal of waste, and disruption in the process of organizations and even outside different organizations.
	33- Distance to military centers and barracks	In humanitarian crises such as war, rebellion, and internal conflicts of military centers
	34- Distance to gas pressure-reducing stations	The construction of urban waste collection and storage systems in the vicinity of gas pressure-reducing stations in times of crises such as earthquakes destroys the equipment of these centers and the spread pollution in the city.
Passive defense (dispersion)	35- Proper dispersion in locating waste collection systems	Uncontrolled construction debris limits access for servicing, recovery, and reconstruction in the area during a crisis. Accumulation of urban waste such as construction debris causes more waste to flow into the area so it becomes a dumping site or illegal disposal of urban waste.

Table 4: Evaluation matrix of FMEA effects of passive defense and environmental risk factors in the location of urban waste collection and storage systems in District 6 of Tehran Municipality, Iran

Criteria	Sub-criteria (risk factors)	Severity of effect	Probability of occurrence	Significance of risk (W_i)	RPN	Level of risk
Socioeconomic	A_1- Population density (the higher the density, the greater the humanitarian crisis)	8	10	0.465	37.2	H
	A_2- Distance to lines of communication (the greater the distance, the less humanitarian crisis)	6	8	0.331	15.8	M
Physical-spatial	A_3- Worn-out texture (the more worn-out texture, the greater the humanitarian crisis)	4	5	0.442	8.8	L
	A_4- Land use (the higher the density of residential use, the greater the humanitarian crisis)	6	7	0.246	10.3	M
	A_5- Proximity to high-traffic roads (The greater the distance to the roads, the less the humanitarian crisis)	8	7	0.459	25.2	H
	A_6- Density of parks and green spaces (The greater the density of parks and green spaces, the less the humanitarian crisis)	7	4	0.128	3.5	L
	A_7- Distance to health centers (The greater the distance, the less the humanitarian crisis)	4	4	0.259	6.2	L
	A_8- Distance to the nearest fire station (The more distance, the more humanitarian crisis)	6	7	0.273	11.4	M
	A_9- Distance to the next trash can (The more distance, the less humanitarian crisis)	4	10	0.247	9.8	L
	A_{10}- Distance to sensitive military places (The more distance, the less humanitarian crisis)	6	7	0.332	13.9	M
	A_{11}- Distance to facilities and infrastructure network (water supply network, power lines, sewage network, telecommunications, etc.) the greater the distance, the less humanitarian crisis	5	7	0.192	6.7	L
	A_{12}- Distance to historical and religious places and monuments in the region (The greater the distance, the less the humanitarian crisis)	10	6	0.073	4.3	L
	A_{13}- Distance to sensitive areas with special ecosystems (The greater the distance, the less the humanitarian crisis)	4	5	0.148	2.9	L
Hydrological-climatic	A_{14}- Distance to watercourses and canals (The greater the distance, the less the humanitarian crisis)	7	5	0.244	8.5	L
	A_{15}- Wind direction (The higher the wind speed, the lower the value)	7	10	0.284	19.8	M

	A_{16}- Depth of aqueduct (The greater the distance to the aqueduct, the less the humanitarian crisis)	10	5	0.062	3.1	L
	A_{17}- Well depth (The greater the distance to the well, the less the humanitarian crisis)	7	7	0.464	22.7	H
	A_{18}- Distance to water facilities and tanks (The greater the distance, the less the humanitarian crisis)	6	7	0.175	7.3	L
	A_{19}- Distance to water and wastewater treatment plant (The greater the distance, the less the humanitarian crisis)	6	5	0.055	1.6	L
Geological	A_{20}- Distance to a fault (The greater the distance, the less the humanitarian crisis)	6	8	0.601	28.8	H
	A_{21}- Soil type (The finer the soil, the less the humanitarian crisis)	4	3	0.203	2.4	L
	A_{22}- Slope (The higher the slope, the greater the humanitarian crisis)	6	4	0.101	2.4	L
	A_{23}- Bedrock type (The more impenetrable the bedrock and the harder the formations, the less the humanitarian crisis)	6	9	0.137	7.3	L
Passive defense (high-risk facilities)	A_{24}- Distance to power substation (The greater the distance, the less the humanitarian crisis)	8	10	0.389	31.3	H
	A_{25}- Distance to overhead power lines (The greater the distance, the less the humanitarian crisis)	4	5	0.570	11.4	M
	A_{26}- Distance to gas installations (The greater the distance, the less the humanitarian crisis)	5	6	0.265	7.9	L
	A_{27}- Distance to oil and diesel tank stations (The greater the distance, the less the humanitarian crisis)	6	5	0.138	4.1	L
	A_{28}- Distance to the gas station (The greater the distance, the less the humanitarian crisis)	3	2	0.089	0.53	L
	A_{29}- Distance to oil tanks and warehouses	3	5	0.157	2.3	L
Passive defense (lifeline)	A_{30}- Distance to subway (lifeline)	5	6	0.089	2.6	L
	A_{31}- Distance to telecommunications (lifeline)	8	3	0.037	0.8	L
	A_{32}- Distance to administrative centers	5	6	0.145	4.3	L
	A_{33}- Distance to military centers and barracks	2	1	0.008	0.01	L
	A_{34}- Distance to gas pressure-reducing stations	4	3	0.093	1.1	L
Passive defense (dispersion)	A_{35}- Proper dispersion in locating waste collection systems	3	6	0.107	1.9	L

In general, risks cannot be eliminated, but they can be reduced to an acceptable or tolerable level. Therefore, risk management aims to establish a systematic and continuous framework to identify, evaluate, eliminate, control, prevent, reduce and introduce risks [34]. During the risk management process, decisions are made based on the comparison of risk assessment results and determining risk levels. Jalilzadeh Yengejeh and Rahmani (2021) [35] evaluated the risk of particulate matter through EFMEA and TOPSIS techniques in district 9 of Tehran Municipality (Iran) and identified seven criteria with 17 sub-criteria, of which two criteria had the greatest impact on regional public health. In the present research, seven criteria with 35 sub-criteria were identified and five effective risk factors were introduced in the location of urban waste collection and storage systems in district 6 of Tehran Municipality. In addition, Rezaian et al. (2017) [36] assessed the environmental risk in the Shohadaye Khalij Fars Agro-industrial Complex (Ahvaz, Iran) using the TOPEFMEA method. It was found that the infiltration of pollutants and chemicals from the sugar production process into water resources was the priority (RPN = 16) among other activities. They suggested the use of the integrated TOPSIS-FMEA method to reduce the most important risk factors, and in line with the present research, they emphasized the use of the optimal TOPEFMEA method for risk identification, assessment, and ranking. In this research, the TOPSIS ranking results showed that the sub-criterion of "Distance to nearest fire station" (cl_i=0.861) was the highest risk factor. Rezvani et al. (2018) [37] evaluated the safety and health risk of Ilam Gas Refinery (Iran) using the multi-criteria evaluation technique and the TOPSIS method. In the health risk assessment, poisoning and the impact on employee health caused by microbial factors (cl_i = 0.66) were identified as the highest health risk. Further, in the safety risk assessment, life and financial damage, burns, and death caused by fire due to the storage of flammable materials in the warehouse (cl_i = 0.56) were identified as the highest safety risk. In conclusion, they proposed TOPSIS as a new method that can be used in risk ranking and assessment. The most significant feature of this method, which is the reason for its usefulness in evaluating and ranking risks, is its high power in choosing the most ideal solution. Such an advantage stems from the compensatory nature of the method and the ability of the criteria to overlap with each other. Unlike other applied methods in risk assessment, such as FMEA, which evaluate each criterion separately, the TOPSIS method evaluates the criteria together and based on all data, so that the smallest change in the values of the decision matrix items affects the entire assessment results. The other most important advantages of this method are the possibility of applying Excel spreadsheets and other software to perform TOPSIS calculations, flexibility, no restrictions on the number of options and criteria, the possibility of using experts' opinions in weighing the options, and the ability to integrate with other decision-making approaches. In this context, Saati et al. (2007) and Sekhavati and jalilzadeh [38,39] also emphasize the effectiveness of this method in managerial decision-making.

Table 5: Values of positive and negative ideal solutions for environmental risk and passive defense criteria effective in locating municipal waste collection and storage systems in District 6 of Tehran Municipality, Iran

Criteria / Ideal solutions	Severity of effect	Probability of occurrence	Significance of risk	RPN
A^+	0.28	0.276	0.369	0.475
A^-	0.056	0.027	0.005	0.00

Table 6: Relative similarity coefficient and normalized (standardized) matrix for environmental and passive defense risks effective in locating urban waste collection and storage systems in District 6 of Tehran Municipality, Iran

Risk Alternative (Number)	Severity	Occurrence	Significance	RPN	Cl_i	The final rank of risks
A_1	0.224	0.266	0.286	0.475	0.861	1
A_2	0.168	0.213	0.203	0.202	0.510	7
A_3	0.112	0.133	0.271	0.112	0.420	10
A_4	0.168	0.186	0.151	0.131	0.392	13
A_5	0.224	0.186	0.276	0.321	0.702	4
A_6	0.196	0.106	0.079	0.045	0.250	24
A_7	0.168	0.106	0.159	0.079	0.312	20
A_8	0.168	0.186	0.168	0.145	0.417	11
A_9	0.112	0.266	0.152	0.125	0.413	12
A_{10}	0.168	0.186	0.204	0.177	0.474	9
A_{11}	0.140	0.186	0.118	0.085	0.319	19
A_{12}	0.280	0.160	0.045	0.055	0.332	17
A_{13}	0.112	0.133	0.091	0.037	0.214	27
A_{14}	0.196	0.133	0.150	0.108	0.357	14
A_{15}	0.196	0.266	0.174	0.253	0.573	6
A_{16}	0.280	0.133	0.038	0.040	0.310	21
A_{17}	0.196	0.186	0.285	0.290	0.661	5
A_{18}	0.168	0.186	0.107	0.093	0.331	18

A_{19}	0.168	0.133	0.034	0.020	0.212	28
A_{20}	0.168	0.213	0.369	0.367	0.774	2
A_{21}	0.112	0.080	0.125	0.031	0.205	30
A_{22}	0.168	0.106	0.062	0.031	0.209	29
A_{23}	0.168	0.240	0.084	0.093	0.355	15
A_{24}	0.224	0.266	0.239	0.397	0.771	3
A_{25}	0.112	0.133	0.350	0.145	0.500	8
A_{26}	0.140	0.160	0.163	0.101	0.346	16
A_{27}	0.168	0.133	0.085	0.052	0.252	23
A_{28}	0.084	0.053	0.055	0.007	0.091	34
A_{29}	0.084	0.133	0.096	0.029	0.203	32
A_{30}	0.140	0.160	0.055	0.033	0.228	25
A_{31}	0.224	0.080	0.023	0.010	0.225	26
A_{32}	0.140	0.16	0.089	0.055	0.259	22
A_{33}	0.056	0.027	0.005	0.000	0.000	35
A_{34}	0.112	0.080	0.057	0.014	0.134	33
A_{35}	0.084	0.160	0.066	0.024	0.204	31

4. Conclusion

The data analysis in the present research identified and evaluated the effective risk factors in the location of mechanized systems for collecting and storing urban waste in district 6 of Tehran Municipality in the form of seven main criteria (socioeconomic, geological, physical-spatial, hydrological-climatic, three passive defenses (high-risk facilities, lifeline, and dispersion) and 35 sub-criteria. Based on the results of the FMEA method, the environmental and passive defense risk factors were classified into three levels (high, medium, low), of which 69% were in the low level, 17% in the medium level, and 14% in the high level. TOPSIS ranking results identified "Distance to nearest fire station", "Distance to fault" and "Distance to power substation" as the highest risk factors with similarity to ideal solution (cl_i) values of 0.861, 0.774, and 0.771, respectively. On the other hand, "distance to gas pressure-reducing stations" with cl_i of 0.134 was determined as the least important risk factor. Our findings confirmed TOPSIS as a new approach, which, if combined with other assessment methods such as FMEA, can be used to rank and evaluate risks.

Authors' Contributions

Mohsen Amiri: preparation of the introduction sections; data collection and analysis; completion of the discussion section of the article. Mojgan Zaeimdar: writing the research method of the article. Hamidreza Khaledi: data analysis. Sahar Rezayan: data analysis and research conclusions.

Conflicts of Interest

The authors declare no conflicts of interest.

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