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Prioritizing health, safety and environmental hazards by integrating risk assessment and analytic hierarchy process techniques in solid waste management facilities

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ABSTRACT

The aim of this research was to assess and prioritize risk levels of health, safety, and environmental (HSE) hazards in solid waste management facilities of Tehran, Iran. The risk of HSE hazards was assessed using Fine-Kinney and environmental failure mode and effects analysis (EFMEA) methods and then the high-risk hazards were prioritized for implementing corrective actions by analytic hierarchy process (AHP) considering six criteria of (1) probability of occurrence, (2) severity of consequences, (3) simultaneous HSE effects, and (4-6) feasibility, effectiveness, and cost of corrective actions. A total number of 485 HSE hazards were identified, of which 78% were health and safety hazards and 22% were environmental hazards. The proportions of the transfer and transport, material recovery and composting facilities and landfill sites in the identified hazards were 21%, 38%, and 41%, respectively. Based on the AHP method, the leading hazards in the transfer and transport, material recovery and composting facilities, and landfill sites were exposure to bioaerosol in carwash facilities, exposure to bioaerosols and odor/volatile organic compounds (VOCs) in manual waste separation, and leachate spills in the former landfill site, respectively. This study showed that the hybrid method was an appropriate and reliable tool to prioritize HSE hazards.

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Environmental hazard; occupational health and safety; risk assessment; risk management; solid waste management

Introduction

Population and economic growth, urban development, and rising living standards have led to increased solid waste generation in various countries all around the world.[1,2] The annual amount of municipal solid waste generated worldwide in 2019 was 2.01 billion tonnes that is expected to reach 3.40 billion tonnes by 2050.[3–5] As a result of the increase in the quantity and diversity of generated solid waste, the importance of environmentally sound waste management is doubled and poor implementation of solid waste management principles can create widespread and irreparable health, safety, and environmental (HSE) hazards. A part of the HSE hazards are associated with chemical and microbial contaminants and spontaneous biological reactions of materials in the waste composition, and other ones are related to the operation and use of machinery and various processes during storage, collection, transfer and transport, processing, recycling, material transformation, and waste disposal in landfill sites.[2,6–9]

Some of the solid waste management hazards such as chemical and microbial contaminants, odor emission, impressive proliferation of insects, rodents, and other vermin, noise, and environmental pollution not only threaten waste management staff, but also have adverse public health effects, while some other hazards, such as occupational accidents, only affect the employees.[10–14] One of the most important and necessary actions in solid waste management systems is risk assessment and management of the HSE hazards. The risk assessment of HSE hazards is performed in four steps, including (1) hazard identification, (2) determining the causes and probability of occurrence of the event, (3) determining the event consequences and their severities, and (4) calculating and classifying the risk levels. In the risk management, control measures are selected and implemented based on the output of risk assessment. The risk assessment and management processes can significantly prevent morbidity and mortality rates, costs, and property damages of the HSE hazards.[15–17] There are a number of

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quantitative, qualitative, and hybrid methods for the HSE risk assessment such as the failure mode and effect analysis (FMEA), fault tree analysis (FTA), Fine-Kinney, environmental failure modes and effects analysis (EFMEA), and event tree analysis (ETA) techniques.[18–20] In order to achieve more effective risk management, consideration should be given not only to the level of risks, but also to the feasibility, efficiency, and cost of corrective actions. For prioritizing corrective actions, multi-criteria decision-making (MCDM) approaches such as analytic hierarchy process (AHP) can be efficient methods. In the previous studies, the MCDM methods have been used to manage HSE risks in different industries such as parts manufacturing, construction projects, power plants, rail transportation system, and airports in order to achieve optimum corrective measures.[18,21,22]

The Fine-Kinney and EFMEA are two of the most well-known and widely used methods for HSE risk assessment due to a number of desirable characteristics such as, quantitatively scoring, considering important aspects of hazards, being user friendly, acceptable accuracy and sensitivity, and rapid assessment. For all the benefits, the risk assessment methods exhibit some limitations including, subjective judgments and biases, lack of weighting the input factors, and failure to consider the feasibility, efficiency, and cost of corrective actions. The combination of the Fine-Kinney and EFMEA methods with the AHP approach can reduce the pitfalls and reinforce the benefits to achieve more effective HSE risk management.[23–29] Due to the variety and multiplicity of HSE hazards and their relatively high-risk levels in solid waste management facilities, introducing and applying hybrid models based on the Fine-Kinney, EFMEA, and AHP approaches can help to overcome the challenging issues of HSE risk management in the facilities. In this study, the risk of HSE hazards of the solid waste management facilities in Tehran was assessed in three parts of transfer and transport, material recovery and composting facilities, and landfill sites by the Fine-Kinney and EFMEA methods and then the high-risk hazards were prioritized for implementing corrective actions by the AHP.

Materials and methods

Study area and procedures

Tehran is the capital city of Iran and Tehran Province. Tehran with an area of 720 km^2 and a population of more than 8,700,000 is the largest and the most populous city in Iran. In 2019, the average amount of collected municipal solid waste in Tehran was 5,352 tonnes per day, resulting in a per capita value of 0.85 kg per day. The contributions of generation resources in municipal solid waste in Tehran were as follows: 66.4% for residential resources, 24.6% for commercial and institutional resources, 1.1% for healthcare facilities, 0.2% for industrial resources, and 7.7% for other resources. It should be noted that the municipal solid waste statistics do not include construction and demolition waste and those separated by waste pickers. The production of construction and demolition waste in the city in 2019 was 45,440 m^3/d, of which 12,090 m^3/d was transferred to the recycling centers and transformed to 10,640 m^3/d of recycled construction materials (mainly sand). The other construction debris was disposed of in Abali landfills and permitted waste holes. The general route of solid waste management in Tehran was started with collecting waste from mechanized containers and transferring them to 20 transfer stations. In the transfer stations, solid waste was transferred from collection trucks to transport ones and then delivered to the comprehensive solid waste management facility of Tehran in Kahrizak. In the facility, the solid waste was transferred to 10 processing halls, then in the subsequent stages was divided into three categories: (1) recyclable components that were packed and sold, (2) compostable waste that was transformed to compost by the windrow method, and (3) unusable solid waste that were disposed of at the sanitary landfill cells.

This article does not contain any studies involving human participants performed by any of the authors. The study was performed in three parts of solid waste management facilities of Tehran to be transfer and transport, material recovery and composting facilities, and landfill sites. First, the risk of health and safety hazards was assessed using the Fine-Kinney method and the risk of environmental hazards was assessed using the EFMEA method. Then, an expert panel consisting of 12 academic and executive experts in the fields of Environmental Health (4 members), Occupational Health (2 members), HSE Management (4 members), and Safety Engineering (2 members) was established to determine and weight the criteria of prioritizing the high-risk HSE hazards for implementing control measures. Finally, the high-risk hazards were ranked and prioritized based on expert panel opinions using the AHP method by pairwise comparisons. Figure 1 shows the flowchart of techniques and steps applied in this study.

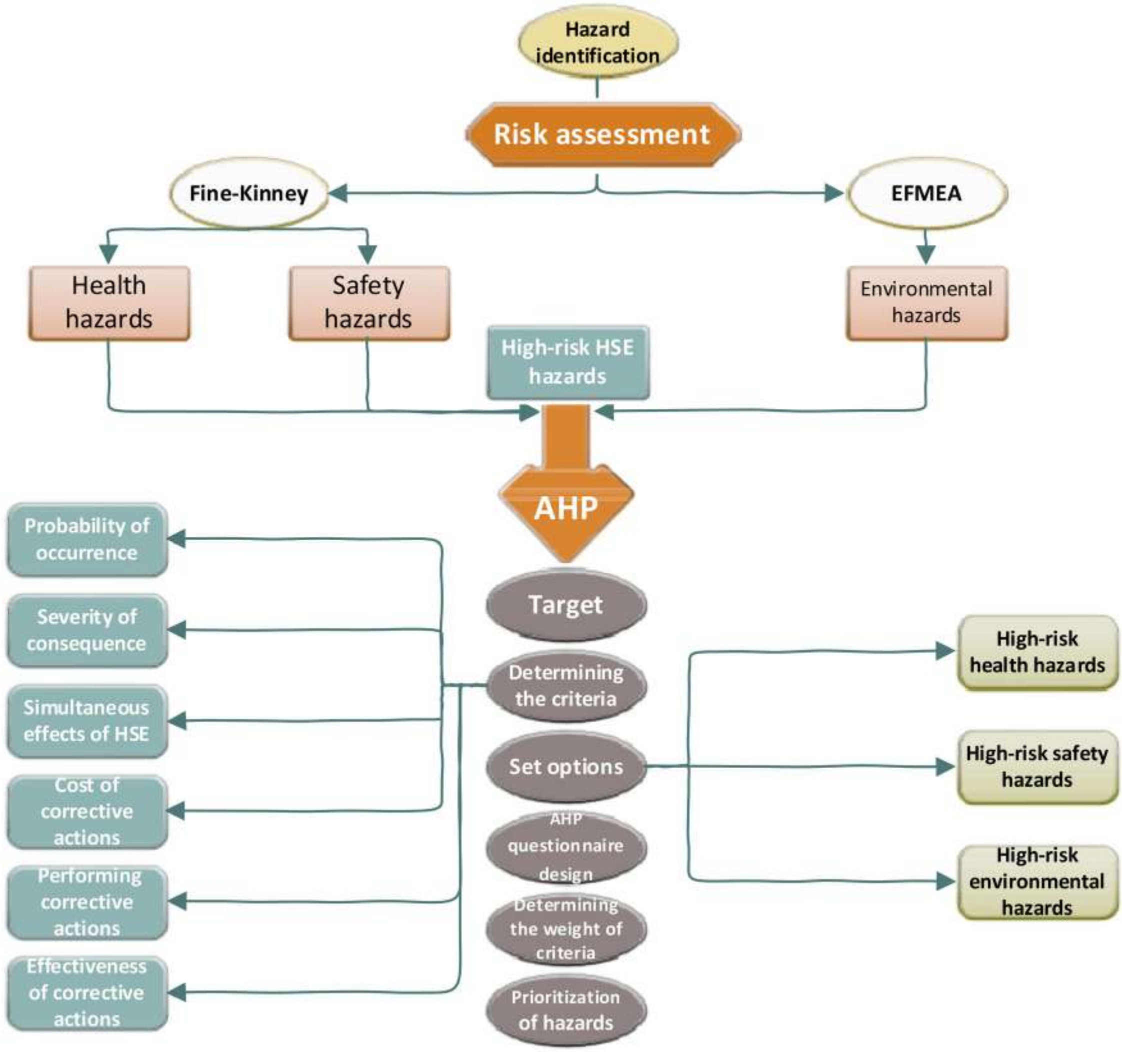

Figure 1. Flowchart of techniques and steps applied in this study.

Fine-Kinney method

The Fine-Kinney method as a quantitative risk assessment technique was developed by Kinney and Wiruth in 1976.[30] The most important advantages of this method are considered to be ease of use, quantitative risk analysis and rating, and acceptable accuracy and sensitivity.[31] There are three factors in this risk assessment method including, (1) degree of exposure (E_{hs}), (2) probability of occurrence (P_{hs}), and (3) severity of consequences (S_{hs}). The risk score of health and safety hazards (R_{hs}) is obtained by multiplying the three factors as follows[18,27,30,31]:

$$R_{hs} = E_{hs} \times P_{hys} \times S_{hs} \quad (1)$$

The scores of exposure level, probability of occurrence, and severity of consequences in the Fine-Kinney method are described in Table S1 in supplementary materials.[18,27,30,31]

EFMEA method

The EFMEA is a method of environmental risk assessment and one of the sub-branches of the FMEA[24] in which, in addition to reviewing and analyzing the various aspects of hazards, the affected area is also identified and environmental sensitivity and specific values of the area are considered.[24,32] The consequences of environmental aspects are divided into two categories: environmental pollution and the consumption of resources (materials and energy). The environmental risk score (R_e) is calculated by multiplying the three factors of event detectability (D_e), probability of occurrence (P_e), and severity of environmental impacts (S_e) as below[24,28]:

$$R_e = D_e \times P_e \times S_e \quad (2)$$

The scores of event detectability, probability of occurrence, and severity of environmental impacts in

Table 1. Risk score clusters in the Fine-Kinney risk assessment method.[20,24,29,30]

No.	Risk score range	Risk cluster	Action
1	Higher than 400	Very high	The activity should not be performed until corrective action is taken.
2	200-400	High	Corrective action must be taken immediately.
3	70-200	Medium	Corrective action is required.
4	20-70	Low	Attention should be paid as soon as possible.
5	Lower than 20	Acceptable	No corrective action is required.

the EFMEA method are described in Table S2 in supplementary materials.[24,28]

Risk score interpretation

The risk score clusters of health and safety hazards in the Fine-Kinney method are provided in Table 1.[18,27,33] To classify the environmental hazard risk score (EFMEA results), interval from average was used, so that the risk scores over average plus standard deviation ($\mu + \sigma$) were considered as high risk (High), the risk scores between μ - σ and $\mu + \sigma$ were considered as medium risk (Medium), and risk scores lower than μ - σ were considered as low risk (Low).[23,25,34–36]

Prioritization of HSE hazards using AHP method

The AHP method is one of the most popular MCDM techniques based on the pairwise comparison.[37–39] After the risk assessment, the high-risk HSE hazards (risk scores higher than 200 for health and safety hazards and risk scores higher than $\mu + \sigma$ for environmental hazards) were prioritized for implementing corrective actions using the AHP method with the Expert Choice software.[40] For prioritizing the hazards, six criteria, including the probability of occurrence, severity of consequences, simultaneous effects of health, safety, and environment, feasibility of control measures, effectiveness of control measures, and cost of control measures were selected and by the expert panel. Similar to prioritizing the HSE hazards, weighting the AHP criteria were conducted by the expert panel using pairwise comparison with a 9-point scoring scale.

Results

Risk assessment of HSE hazards

A total number of 485 HSE hazards were identified in the transfer and transport, material recovery and composting facilities, and landfill sites in Tehran using verified checklists, interviews and site visits, of which 78% were related to health and safety (376 hazards) and 22% were environmental hazards (109 cases). The contributions of the transfer and transport, material recovery and composting facilities, and landfill sites in the identified hazards were 21%, 38%, and 41%, respectively. The risk levels of safety and health hazards based on the Fine-Kinney method in different parts of solid waste management facilities of Tehran are shown in Figure 2. As shown in Figure 2, the shares of the transfer and transport, material recovery and composting facilities, and landfill sites in the health and safety hazards were 16%, 43%, and 41%, respectively. In the entire waste management facilities, more than 60% of the health and safety hazards were within the acceptable and low ranges, and the share of high and very high risks was 4%. The material recovery and composting facilities had a greater share in the health and safety hazards than the transfer and transport and landfill sites. In the material recovery and composting facilities, the level of the health and safety risks was also somewhat higher than the other sectors, mainly due to the more dangerous nature of activities in the facilities.

The risk levels of environmental hazards based on the EFMEA method in different parts of the waste management facilities of Tehran are presented in Figure 3. The distribution of environmental hazards in the solid waste management facilities of Tehran in low-, medium-, and high-risk levels were 14%, 63%, and 23%, respectively. The proportions of the transfer and transport, material recovery and composting facilities, and landfill sites in the environmental hazards were 39%, 19%, and 41%, respectively. Contrary to the health and safety hazards, the material recovery and composting facilities had a lower share in environmental hazards than the transfer and transport and landfill sites, but the risk levels of environmental hazards in the facilities were much higher than those in the other sectors, so that the percentages of low-, medium-, and high-risk levels of environmental hazards in the material recovery and composting facilities were determined to be 10%, 14%, and 76%, respectively.

Figure 4 shows the frequency distribution of health and safety hazards into the physical, chemical, biological, ergonomic, and safety groups in the solid waste management facilities of Tehran. The proportions of safety, physical, chemical, biological, and ergonomic hazards in the entire waste management facilities were 38%, 23%, 14%, 13%, and 11%,

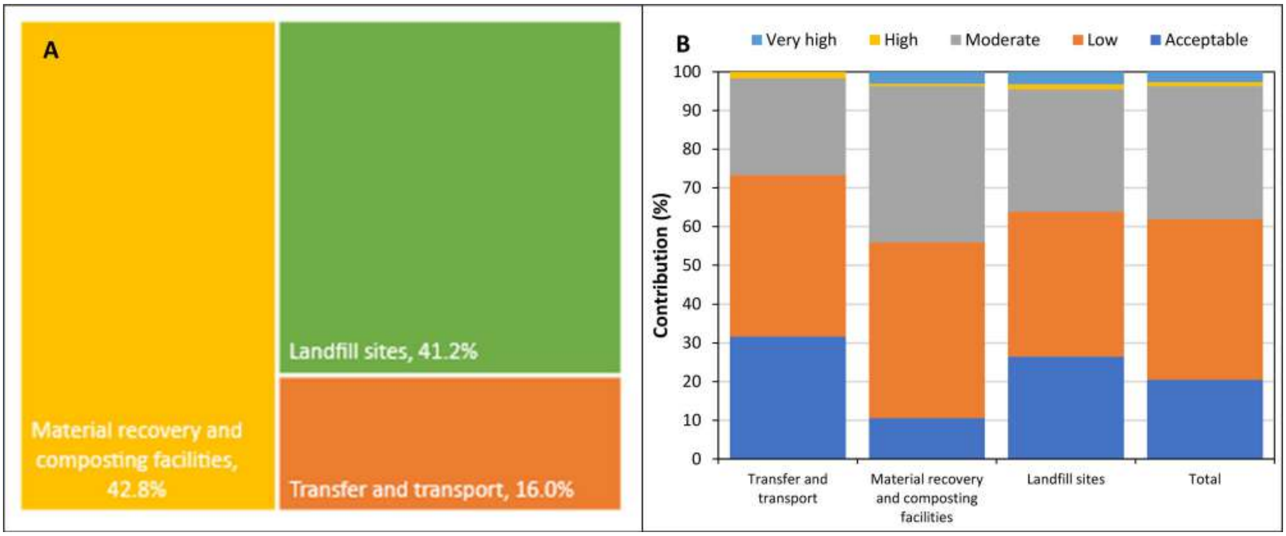

Figure 2. Risk levels of safety and health hazards based on the Fine-Kinney method in the different parts of solid waste management facilities of Tehran (total number of hazards: 376 cases).

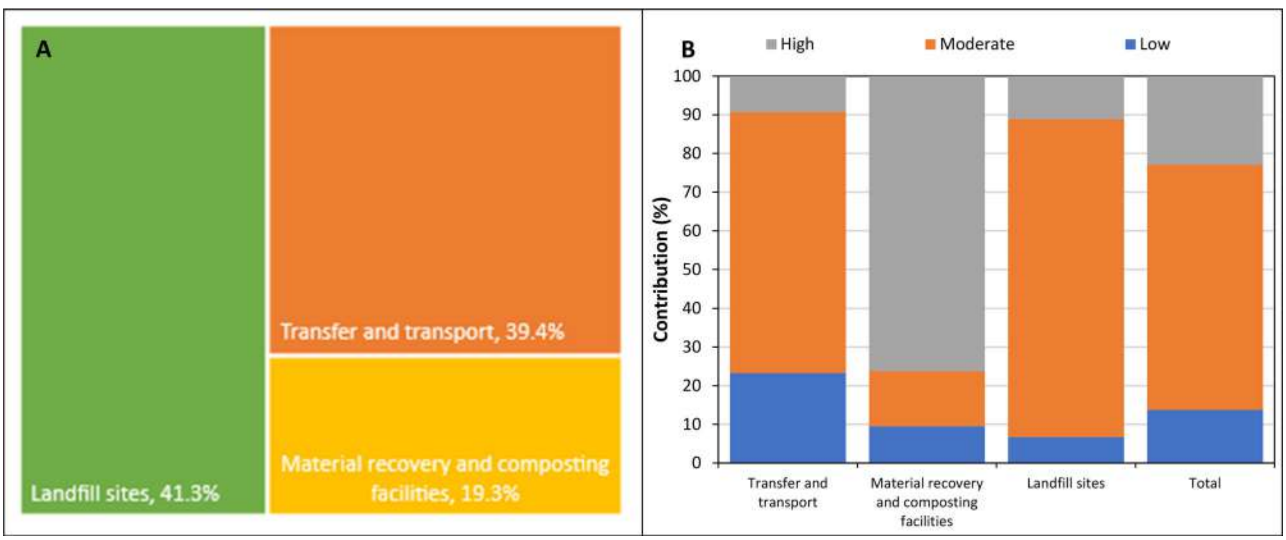

Figure 3. Risk levels of environmental hazards according to the EFMEA method in different parts of solid waste management facilities of Tehran (total number of hazards: 109 cases).

respectively. According to Figure 4, the distribution of hazard groups in different parts of the waste management facilities was to an extent different. The highest portions of the health and safety hazards in the transfer and transport, material recovery and composting facilities, and landfill sites were related to safety hazards (44%), physical hazards (35%), and safety hazards (46%), respectively, and the lowest ones were related to chemical hazards (11%), ergonomic hazards (9%), and ergonomic hazards (12%), respectively.

Prioritization of HSE hazards by AHP method

The AHP method was applied to prioritize high-risk hazards for implementing corrective actions. The weights of the criteria used in the AHP method to prioritize the HSE hazards were as follows: 0.289 for the severity of consequences, 0.253 for the probability of occurrence, 0.158 for simultaneous effects of HSE, 0.118 for the effectiveness of corrective actions, 0.097 for feasibility of corrective actions, and 0.085 for the cost of corrective actions (Figure 5). The total weight of the criteria related to corrective action was determined to be 0.300.

The number of high-risk hazards in the transfer and transport, material recovery and composting facilities, and sanitary landfills were 10, 9, and 12, respectively. Figure 6 shows the prioritization of the high-risk HSE hazards based on the weights obtained by the AHP method and the normalized risk scores in

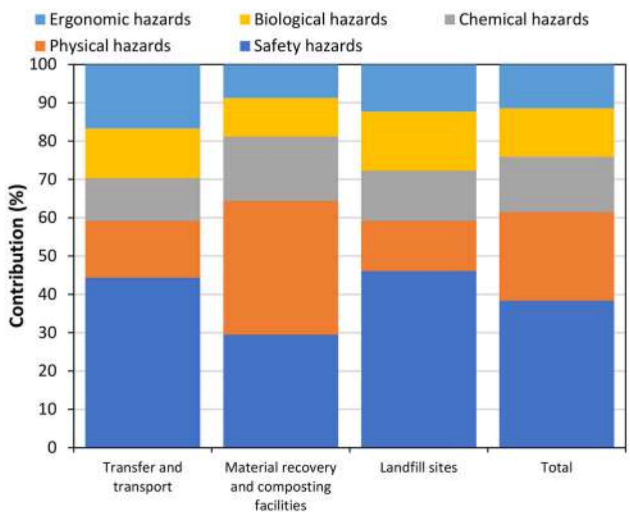

Figure 4. Frequency distribution of health and safety hazards by physical, chemical, biological, and safety groups in the solid waste management facilities of Tehran.

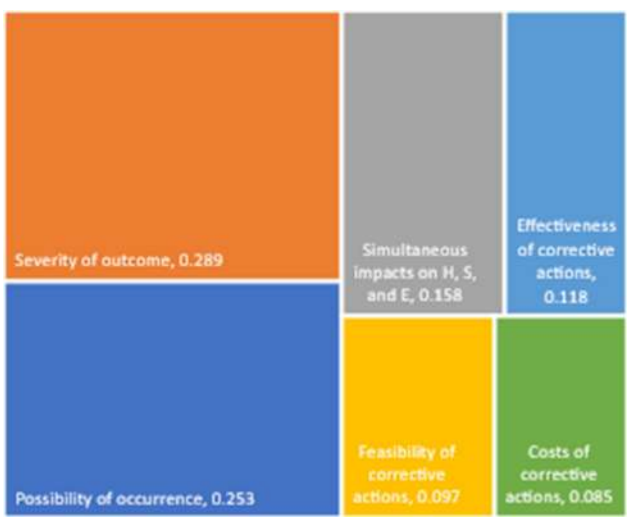

Figure 5. The weights of criteria used in the AHP method to prioritize the HSE hazards in the solid waste management facilities of Tehran.

different parts of the solid waste management facilities of Tehran. The following equations were used to normalize the risk scores:

$$R_i' = \frac{R_i}{R_h} \tag{3}$$

$$R_i'' = \frac{R'}{\sum_{i=1}^{n} R_i'} \tag{4}$$

where R_i is the risk score of hazard i, R_h is the upper limit of the risk score of hazards (1000) and R'' is the normalized risk score of hazard i.

The weights of hazards obtained by the AHP method and their normalized risk scores were compared by paired t-test. The weights of the HSE hazards obtained by the AHP method in different parts of the solid waste management facilities of Tehran were significantly different from their normalized risk scores (p value <0.001); therefore, the prioritization of the AHP method was remarkably different from the results of risk assessment methods and the results of the AHP method could be more valid due to considering the criteria of corrective actions and also the opinions of the expert panel.

As indicated in Figure 6, in the transfer and transport the contributions of health, safety and environmental hazards in the high-risk hazards were, 50% (five hazards), 10% (one hazard), and 40% (four hazards), respectively. In the transfer and transport, 50% of the hazards were related to waste trucks, 20% were related to carwash units (located in the transfer stations), 20% were related to the tire puncture repair units (located in the transfer stations), and 10% were related to the maintenance of transfer stations. The high-risk HSE hazards of waste trucks in the transfer and transport consisted of water and soil pollution caused by leachate spills from waste trucks (second priority with a weight of 0.130), heat stress in driving (sixth priority with a weight of 0.102), emission of air pollutants from waste trucks (seventh priority with a weight of 0.098), poor driving posture (eighth priority with a weight of 0.080), and high fuel consumption in waste trucks (ninth priority with a weight of 0.076). These results indicated that the replacement, renovation, and maintenance of waste trucks and the drivers' training on the proper driving posture can decrease half of the high-risk hazards in the transfer and transport. The high-risk hazards in carwash units were determined to be exposure to bioaerosol (first priority with a weight of 0.130) and high levels of water consumption and pollution loads (fourth priority with a weight of 0.109). These hazards were mainly due to the fact that truck washing was done manually, therefore; mechanizing the truck washing process could significantly reduce workers' exposure to bioaerosols as well as water and detergent consumption and wastewater generation. The high-risk hazards in puncture repair units included noise exposure (third priority with a weight of 0.117) and vibration (tenth priority with a weight of 0.056) that both of them were physical agents. The use of the standard operating procedure (SOP), rubber vibration absorbers, and personal protective equipment (PPE) can greatly fall the risk of these hazards. The only safety hazard in the transfer and transport was falling from a height in repair and maintenance (fifth priority with a weight

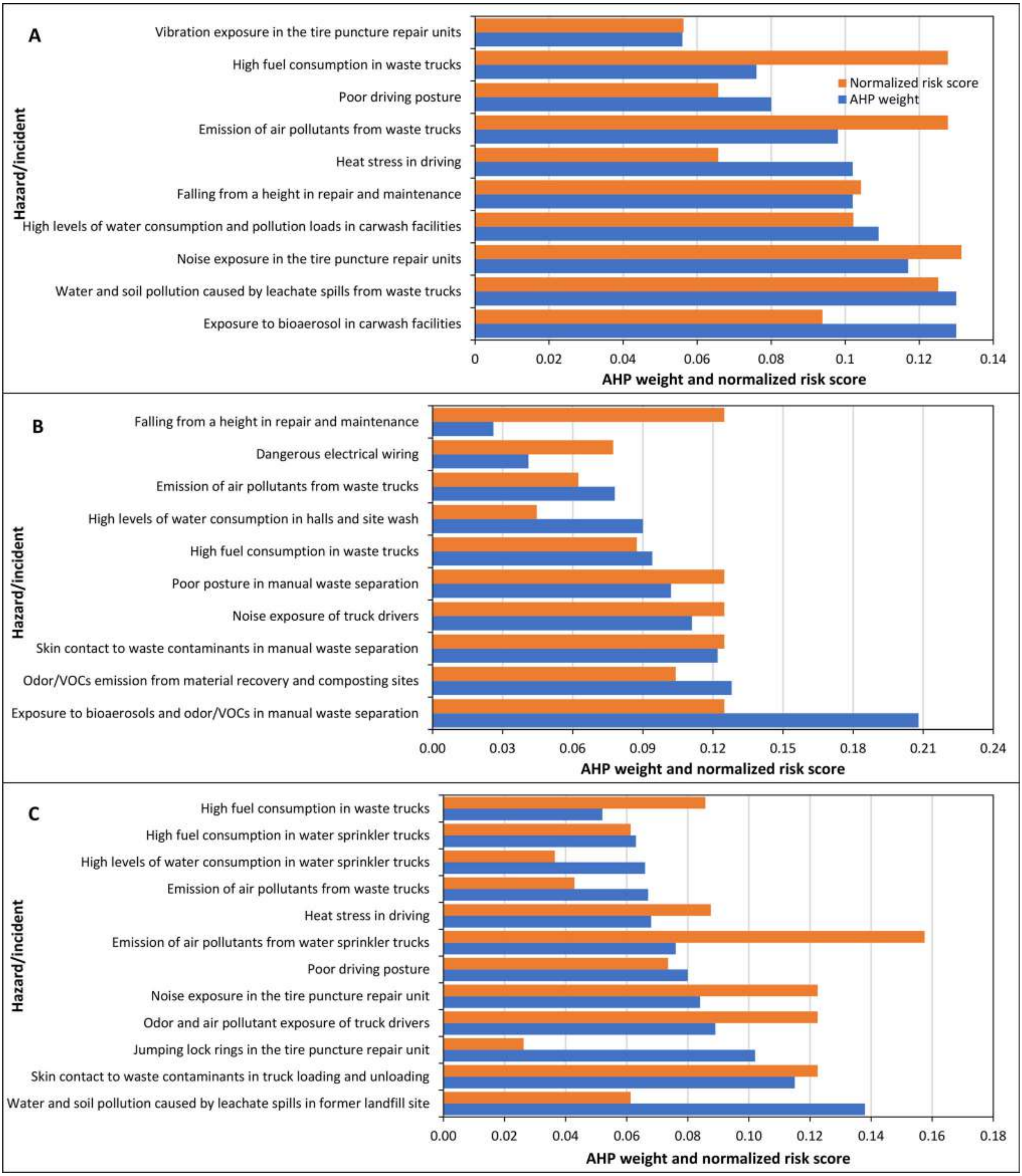

Figure 6. Prioritization of the HSE hazards by the AHP method in different parts of solid waste management facilities of Tehran: (A) transfer stations, (B) material recovery and composting facilities, and (C) landfill sites.

of 0.102), which related corrective actions could be the use of SOP and work safety belts.

The material recovery and composting facilities exhibited 10 high-risk hazards, including four health hazard (40%), two safety hazards (20%), and four environmental hazards (40%). In the material recovery and composting facilities, 33% of high-risk hazards were related to manual waste separation which were exposure to bioaerosols and odor (first priority with a weight of 0.258), skin contact to waste contaminants (second priority with a weight of 0.162), and poor posture (fourth priority with a weight of 0.107). The most important environmental problem in the material recovery and composting facilities was determined to be the emission of odor and volatile organic compounds (VOCs) which could be felt for kilometers around the facilities and resulted in complaints of people in those areas. In recent years, an unpleasant odor was rarely felt in the whole city of Tehran on some days. Although the main source of the unpleasant odor has not been identified yet, many experts believe that the material recovery and composting facilities could be the probable source of the unpleasant odor. Since the municipal solid waste in Tehran was collected as commingled materials, the solid waste entering the material recover plants was highly polluted and its manual separation was very dangerous, the workers in the manual separation were exposed to very strong odors and elevated levels of air pollutants and a significant part of them were transferred to the ambient air. The main measures to control the HSE hazards in the material recovery plants were recommended to be the separation of recyclable waste at the source of generation, the replacement of manual separation with mechanized separation methods, and the installation of air pollution control equipment in the exhaust vent of the processing hall. The other source of the odor and VOCs emissions was the windrow composting site. Although the optimal operation and control of environmental factors to prevent the occurrence of anaerobic conditions in the composting windrows could decrease the odor and air pollutant emissions, the basic control measure in this regard could be replacement of the windrows with in-vessel composting systems. Three high-risk hazards in the material recovery and composting facilities were identified in waste trucks, including noise exposure of truck drivers (third priority with a weight of 0.131), high fuel consumption (fifth priority with a weight of 0.097), and emission of air pollutants (seventh priority with a weight of 0.088). The corrective actions for waste trucks were already discussed. The other high-risk hazards in material recovery and composting facilities were high levels of water consumption in washing the halls and site (sixth priority with a weight of 0.090), dangerous electrical wiring (eighth priority with a weight of 0.041), and falling from a height in repair and maintenance (ninth priority with a weight of 0.026), respectively. In order to reduce water consumption in washing the halls and sites, washing should be done after the initial dry cleaning and the use of automatic valves is also strongly recommended. There was various electrical equipment in the material recovery halls such as conveyor belt, sieve, pneumatic separator, electrical magnet, etc.; therefore, the standard wiring and placement of electrical wires in ducts are required. During this study, unsafe electrical wiring resulted in a case of short-circuiting and fire, causing significant damage to one of the material recovery halls.

A number of 12 high-risk hazards were identified in the landfill sites, of which the proportions of health, safety, and environmental hazards were 42% (five hazards), 8% (one hazard), and 50% (six hazards), respectively. About 67% of the hazards were related to waste trucks and sprinkler trucks. Since some part of the road between the material recovery and composting facilities and landfill site was unpaved (dirt roads), to prevent dust emissions arising from truck movement, sprinkler trucks were periodically used to spray the road, which was accompanied by a great amount of water and fuel consumption, emission of pollutants, and relevant environmental and health impacts. Therefore, the most important corrective action regarding sprinkler trucks was to pave the road and reduce watering. According to the AHP method, the most important hazard in the landfill sites was water and soil pollution caused by leachate spills at the former landfill site (first priority weighing 0.138). Although currently the input solid waste to the site is disposed in sanitary landfill cells with full consideration to control leachate (reducing generation, collection, and treatment), in the past decades, solid waste generated in Tehran was buried without any control, collection, and treatment of leachate. Due to the lack of leachate control, a pond of leachate was formed next to the former landfill site. The leachate pond has no wall and floor pavement and causes a high potential for water, soil, and air pollution. In recent years, with construction of the sanitary landfill and leachate treatment facilities, in addition to collecting and treating leachate from the new sanitary landfill, the leachate accumulated in the pond is gradually transferred to tankers and transported to the leachate treatment plant, but the current trend is slow and it needs to be accelerated. Among the high-risk hazards at the landfill site, jumping lock rings in the tire puncture repair (third priority with a weight of 0.102) and noise exposure in the tire puncture repair (fifth priority with a weight of 0.084) were related to the tire puncture repair unit. The hazard of jumping lock rings in the tire puncture repair unit can lead to serious injuries and even death of the repairmen. The use of SOP such as the complete evacuation of the tire before the start of repair and the employment of skilled repairmen play an important role in preventing these accidents.

Discussion

Due to the heterogenous quality and pollution of solid waste and the variety of operations and processes involved in solid waste management systems, control of the HSE hazards in the solid waste management facilities is a vital activity and should be taken into more consideration. Some of the HSE hazards identified in this study have also been reported in the previous studies. Yao, et al.[41] determined the main causes of unpleasant odors in different parts of a waste disposal site to be sulfur compounds. Also, the carcinogenic risk of 1,2-dichloroethane and trichloroethylene compounds was calculated to be higher than 10^{-4}, which was considered as a significant health risk for the employees of the site. Moussiopoulos[42] in assessing the safety and health status of Hellenic solid waste management facilities showed that the highest level of hazards was related to material recovery and composting facilities and the high-risk hazards were dust emission, animals, and insects around the site. In the study by Ravindra, et al.,[43] the health hazards of street sweeping, waste collection, waste processing and rag picking in Chandigarh, India were assessed by interviews. Among the workers, 22.2% of waste collectors, 43.2% of street sweepers, and 25.5% of rag pickers did not use any PPE, and the rate of respiratory problems, physical injury, and allergies were reported to be 12.3%-17.6%, 4.9%-44.4%, and 35.3%-48.9%, respectively.

Davoli, et al.[44] by assessing the health risk of the pollutant emissions (dioxins, furans, and polycyclic aromatic hydrocarbons) and chronic exposure of the population to contaminated air, soil, and food in an area of 5 km away from the non-hazardous waste landfill determined that the risks of carcinogenic and non-carcinogenic effects were clearly lower than the acceptable values of the World Health Organization (WHO). Taheri, et al.[45] showed that the principles of environmental health were not implemented in the compost facilities and sanitary landfill site in Tabriz and the corrective measures should be taken into more consideration. Li, et al.[46] compared three options of sanitary landfill, incineration, and composting for solid waste management in Zhangqiu, China in terms of health risks of air emissions. The results showed that composting along with material recovery had the least adverse health effects. Ali, et al.[47] in investigating the health effect of a municipal solid waste dumping site in Khamees-Mushait, Saudi Arabia determined that only the cancer risk level of chromium (Cr) was unacceptable for both children and adults. Kazuva, et al.[48] employed the driving force-pressure-state-impact-response (DPSIR) model and environmental risk index (ERI) for environmental risk assessment in municipal solid waste management system of Dar es Salaam City, Tanzania. During the period 2006-2017, the ERI of the solid waste management system was determined to be at a moderate level (0.4–0.6) with an increasing trend and the existing control measures were not enough to manage the risks. The results of the previous works showed that in some cases the environmental emissions of solid waste management facilities were higher than the allowable limits and could cause adverse health effects[46,49–51]; therefore, based on the evidence of air pollution and leachate spills, environmental monitoring, biomonitoring, and assessment of the relevant health effects should be taken into more consideration in the future studies. It is worth to be noted that collection as a major component of solid waste management was not considered in this research. The previous studies identified considerable HSE hazards in solid waste collection such as musculoskeletal disorders, injury, respiratory disorders, social vulnerabilities, eye and skin infections in waste collectors.[10,52–54] The other limitation of this study was related to no measurement of air pollutant emissions and concentrations in the solid waste management facilities.

The results of this study indicated that the hybrid method consisting of the risk assessment and AHP techniques by integrating HSE hazards, taking into account both risk assessment and management criteria, and reflecting the expert panel opinions was an appropriate and reliable tool to prioritize HSE hazards for implementing corrective actions. The hybrid method also has some limitations such as being more time-consuming, inconsistency in the pairwise comparison of hazards, and the need to form expert panel that can be partially addressed by providing more resources for the HSE management system.

Conclusion

A total number of 485 HSE hazards were identified in the three sections of transfer and transport, material recovery and composting facilities, and landfill sites of the solid waste management facilities of Tehran, which included 376 safety and health hazards (78%), and 109 environmental hazards (22%). The highest portion of the health and safety hazards as well as the highest risk levels of the HSE hazards were related to the material recovery and compost facilities. The significant portions of the high-risk HSE hazards were related to leachate spills in the former landfill site, lack of controlling odor/air pollutant emissions in material recovery and composting facilities, improper operation and maintenance of waste trucks, manual separation of waste in material recovery facilities, and lack of observing HSE considerations in the carwash units and tire puncture units. Based on the AHP method, the HSE risk priorities by simultaneous considering the risk assessment and management criteria were obtained different from those by the risk assessment methods. The results showed that by combining the risk assessment and MCDM techniques, the HSE hazards in the solid waste management facilities were prioritized more confident and the implementation of corrective actions based on the prioritization could improve the efficiency and effectiveness of the HSE risk management.

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Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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