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Quantitative assessment of health, safety, and environment (HSE) resilience based on the Delphi method and analytic hierarchy process (AHP) in municipal solid waste management system: A case study in Tehran

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Abstract

Background: The health, safety, and environment (HSE) resilience is the ability of a system to adapt, resist and cope with the HSE risks in critical situations. In this study, the HSE resilience in solid waste management (SWM) system of Tehran was quantitatively assessed using HSE resilience index (HSE-RI).

Methods: The principles and components of HSE-RI were determined and weighted based on the expert panel opinions using Delphi technique and analytic hierarchy process (AHP). The HSE-RI scores were divided into five categories as very good (80-100), good (65-79), medium (50-64), weak (35-49), and very weak (0-34).

Results: The weights of the HSE-RI principles in the SWM system were determined as follows: 0.376 for top management commitment, 0.149 for awareness and risk perception, 0.144 for preparedness, 0.144 for performance, 0.057 for reporting and just culture, 0.0574 for learning culture, 0.055 for flexibility, and 0.017 for redundancy. The highest and lowest scores of the resilience principles in the SWM system were related to the principles of awareness and risk perception (73.6), and reporting and just culture (45.1), respectively. The HSE-RI score in the SWM system was 62.9 (medium).

Conclusion: The results of this study based on the Delphi method and AHP showed that the HSE resilience in the SWM system of Tehran was not at the desired level. The principles of top management commitment (with the highest weight), reporting and just culture and preparedness (with the lowest scores) were determined as the most effective points for improving the HSE resilience in the SWM system of Tehran.

Keywords: Delphi technique, Analytic hierarchy process, Waste management, Perception, Iran

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Introduction

The industrialization, development of technology and urban services, despite having the benefits to improve the economic situation and the welfare of communities, cause a variety of health, safety and environmental (HSE) hazards (1-3). The presence of HSE hazards in any activity is natural and intrinsic and their complete elimination is impossible; therefore, the goal of HSE management system is to reduce the HSE hazard risk in an acceptable range. The establishment of HSE management system plays an important role in improving the health status of employees, promoting reliability and system safety, and reducing environmental risks. The recent experiences indicate that HSE risk management in any system is very difficult and complex and to achieve the desirable or acceptable status, all the possible approaches, system capabilities, and workforce should be used (4-6). The organizations need to develop their flexibility in highly variable and uncertain situations that enabling them to deal effectively with unexpected events, recover after crises, and reinforce future success. One of the useful measures in this field is resilience (7-13).

Resilience is the intrinsic capacity of the system to adapt before, during and after changes and disturbances; so that the system can continue operations in uncertain conditions (14,15). Since resilience is a relatively new concept, its potential has not yet been fully identified, but the evidence from the previous studies shows that resilience can be completely different by sector and the concept can be also used for control of HSE risks in different industries (14,16-24). The HSE management resilience is the ability of a system to adapt, resist and cope with the HSE risks in critical situations or failure events. Although HSE management resilience cannot be a substitute for all existing HSE risk management methods, it can act as a complement to decrease the existing gaps (9,20-25). The elements of HSE resilience are different by industry and exhibit disparate efficacies. The Delphi technique as a structured communication method based on an expert panel can be applied for determination of the elements of HSE resilience. During the Delphi process in two or more rounds, the range of the experts' opinions decreases and the expert panel converges towards the elements of HSE resilience. The AHP utilizes the experts' experiences to estimate the weights of factors through pair-wise comparisons (26). The AHP can be used for weighting the elements of HSE resilience.

The municipal solid waste management (SWM) system is one of the most important parts of municipal services worldwide. These facilities consist of various sections including collection system, transfer stations, transport system, processing units, material and energy transformation systems (such as composting units and incinerators), and landfill sites. There are several HSE risks in each sector of SWM facilities, and HSE management in the facilities is of importance. Tehran, the capital city of Iran, with more than 10% of the country's population (over 8.5 million people) is the most populated city in Iran. One of the most important challenges of HSE management in Tehran is the SWM. The most important high-risk HSE hazards in the SWM facilities of Tehran have been determined to be leachate spills in landfill site, improper maintenance of waste trucks, lack of odor and air pollutant control in material recovery and composting units, and manual separation of solid waste in material recovery units (26). The HSE resilience provides high potential for coping with the HSE challenges in the SWM facilities of Tehran. Therefore, the purpose of this study was to quantitatively assess the HSE resilience of the SWM facility of Tehran. The HSE resilience index (HSE-RI) was developed by determining the resilience principles and components and weighting them by analytic hierarchy process (AHP). Then, the index was used to determine HSE resilience of the SWM facility of Tehran. Finally, the most effective points for improving HSE resilience in the facility were indicated.

Materials and Methods

Development of HSE-RI

In order to develop the HSE-RI in the SWM system of Tehran, a preliminary list of resilience principles and components was prepared by reviewing the literature (9,17-22). Then, an expert panel consisting of 7 faculty members and 8 executive experts in the field of HSE and resilience engineering was formed to evaluate the selected principles and components of the HSE-RI and complete the list. The final principles and components of the HSE-RI were determined and weighted using the Delphi technique and AHP (Figure 1) by the expert panel.

The expert panel made decision about the inclusion of the components in the HSE-RI using the Delphi technique in three rounds based on the content validity ratio (CVR) regarding necessity and the content validity index (CVI) regarding relevancy and clarity. The necessity of the components was answered by three choices to be "essential", "useful but not essential", and "not necessary". The relevancy and clarity of the components were determined by four choices with a descending order

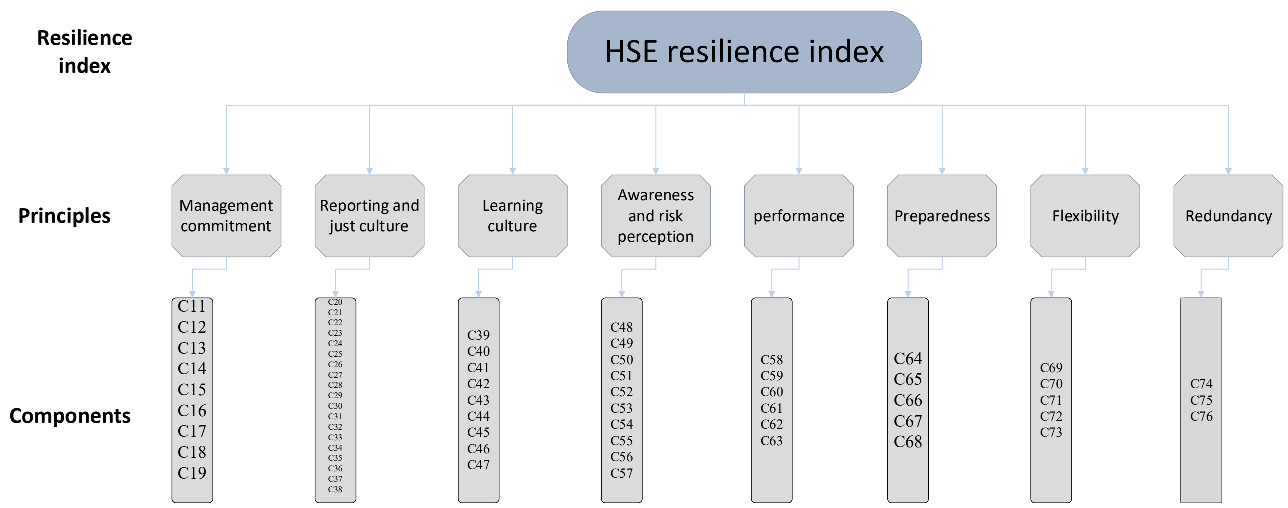

Figure 1. Structure of the AHP model for weighting the principles and components of HSE resilience index

of (4) excellent, (3) good, (2) fair, and (1) poor. The indicators CVR and CVI were calculated by the following equations (22):

$$CVR = \frac{n_E - N/2}{N/2} \quad (1)$$

$$CVI = \frac{n_a + n_b}{N} \quad (2)$$

where N is the number of answers (15 answers from the expert panel), n_E is the number of answers regarding the necessity of the components characterized as "essential", and n_a and n_b are the numbers of answers regarding the quality of the components characterized as "excellent" and "good", respectively. The boundary limits of CVR and CVI for the inclusion of each component were considered to be 0.49 and 0.79, respectively. The final principles and components of the HSE-RI were weighted using the AHP by pairwise comparison of the elements due to the disproportionate contribution of the principles and components to the HSE resilience. The criterion of the AHP was effect size of the final principles and components on the HSE resilience.

The HSE-RI was calculated using the following equations:

$$\mathrm{HSE-RI} = \sum_{i=1}^{m} \left(W_i \times R_i \right) \quad (3)$$

$$R_i = \sum_{j=1}^{n} \left(w_j \times r_j \right) \quad (4)$$

where R_i is the score of resilience principle i, Wi is the weight of resilience principle i, r_j is the score of component j of resilience principle R_i, w_j is the weight of component j of resilience principle R_i, and m and n are respectively the number of principles of HSE-RI and number of components of principle R_i. The components were answered using a 5-point Likert scale and the answers were converted to quantitative scores as follows: 0 for strongly disagree, 25 for disagree, 50 for neither agree nor disagree, 75 for agree, and 100 for strongly agree. The final HSE-RI score (in the range of 0-100) was classified into five categories with a qualitative description based on the opinions of the expert panel to be excellent (80-100), good (65-79), medium (50-64), weak (35-49), and very weak (0-34).

Assessment of the HSE resilience in the SWM system of Tehran

The SWM system of Tehran was divided into three sectors: (1) transfer and transport, (2) processing and composting units, and (3) sanitary landfill site. The HSE resilience of the SWM system of Tehran was quantitatively assessed using the HSE-RI based on the staff feedback. The number of staff samples were determined to be 306 based on the total number of employees of the SWM system (1500 workers) using Cochran's formula. The staff were randomly sampled in the three sectors of the SWM system of Tehran to assess the HSE resilience by sector. The HSE resilience in the sectors was separately examined based on the geographical location, nature of HSE hazards, and exposed population groups. The HSE-RI score of the SWM system of Tehran was determined by weighting the three sectors based on the expert panel opinions (AHP approach) as follows:

$$HSE-RI_t = \sum_{s=1}^{o} \left(W_s \times HSE-RI_s \right) \quad (5)$$

Where $HSE\text{-}RI_t$ is the HSE-RI score of the whole system, W_s is the weight of the sector s of the SWM system, $HSE\text{-}RI_s$ is the HSE-RI score of the sector s of the SWM system, and o is the number of sectors of the SWM system. The weights of transfer and transport, processing and composting units, and sanitary landfill site in the resilience of the whole system were considered to be 0.240, 0.500, and 0.260, respectively. The difference of the average HSE-RI scores between the three sectors of the SWM system was statistically determined by analysis of variance (ANOVA) using SPSS for Windows version 22 software. The effects of the demographic and occupational characteristics of the participants on the HSE-RI scores were analyzed by n-way ANOVA. The HSE-RI as a comprehensive measure of resilience should not be strongly affected by any individual principle (22). In order to investigate the influence of each input principle on the HSE-RI score, sensitivity analysis was conducted by consecutive removing each input parameter from the HSE-RI and comparing the reduced indices to the original one.

Results

Principles and components of HSE-RI

The principles and components of the HSE-RI and their weights are presented in Table 1.

The inconsistency value for the weighting was 0.031, which is less than the maximum desirable value (0.1) (26,27). The weights of the HSE-RI principles were determined to be 0.376 for top management commitment, 0.149 for awareness and risk perception, 0.144 for performance, 0.144 for preparedness, 0.057 for reporting and just culture, 0.057 for learning culture, 0.055 for flexibility, and 0.017 for redundancy. According to Table 1, in three principles of awareness and risk perception, preparedness, and flexibility, the weights of all components by principle were the same. The five components with the highest weights were "top manager's priority over safe work" (0.082, C11 related to the principle of top management commitment), "encourage employees to stop working when there is a defect in health conditions" (0.072, C13 related to the principle of top management commitment), "encourage employees to stop working when accidents are likely to occur due to safety defect" (0.064, C12 related to the principle of top management

Table 1. Principles and components of HSE resilience index and their weights

Principle	Weight	Component			
		Code	Description	Weight in Principle	Weight in HSE-RI
Top management commitment	0.376	C11	Top manager's priority over safe work	0.217	0.082
		C12	Encourage employees to stop working when accidents are likely to occur due to safety defect	0.171	0.064
		C13	Encourage employees to stop working when there is a defect in health conditions	0.190	0.072
		C14	Encourage employees to stop working when there is a defect in environmental protection	0.147	0.055
		C15	Top manager's priority over solving the root of the problem instead of finding and blaming the culprit	0.034	0.013
		C16	Provide the necessary resources to maintain and improve the safety situation by top management	0.068	0.026
		C17	Provide the necessary resources to maintain and improve the health status of employees by top management	0.068	0.026
		C18	Provide the necessary resources to maintain and improve the environmental protection by top management	0.055	0.021
		C19	Awareness of top management about the factors that threaten the activities of the organization	0.051	0.019
Reporting and just culture	0.057	C20	Possibility of consulting with a supervisor when there is a concern about work safety	0.016	0.001
		C21	Possibility of consulting with a supervisor when there is a concern about health status	0.016	0.001
		C22	Possibility of consulting with a supervisor when there is a concern about environmental protection	0.016	0.001
		C23	Existence of a system for recording and reporting accidents and incidents	0.011	0.001
		C24	Existence of a system for recording and reporting health hazards	0.012	0.001
		C25	Existence of a system for recording and reporting environmental hazards	0.009	0.001
		C26	Reporting the workplace safety issues to the supervisor	0.024	0.001
		C27	Reporting the workplace health issues to the supervisor	0.024	0.001
		C28	Reporting the workplace environmental issues to the supervisor	0.024	0.001
		C29	Rewarding to the active employees in improving and promoting workplace safety	0.048	0.003
		C30	Rewarding to the active employees in improving and promoting workplace health	0.050	0.003
		C31	Rewarding to the active employees in improving and promoting workplace environment	0.051	0.003
		C32	The influence of employees on the manager or supervisor decisions	0.105	0.006
		C33	Participatory decision-making on the HSE-related issues	0.105	0.006
		C34	Involvement of staff at all levels and departments in the HSE-related meetings	0.062	0.004
		C35	The tangible spirit of teamwork	0.099	0.006
		C36	Considering the safety performance of employees in their evaluation	0.109	0.006
		C37	Considering the health performance of employees in their evaluation	0.109	0.006
		C38	Considering the environmental performance of employees in their evaluation	0.109	0.006
Learning culture	0.057	C39	Discussion and exchange of views on the HSE-related topics	0.063	0.004
		C40	Learning from accidents	0.231	0.013
		C41	Efforts to promote the HSE culture	0.070	0.004
		C42	Organizing regular occupational safety retraining courses	0.143	0.008
		C43	Organizing regular occupational health retraining courses	0.142	0.008
		C44	Organizing regular environmental protection retraining courses	0.103	0.006
		C45	Existence and continuous updating of safety instructions	0.070	0.004
		C46	Existence and continuous updating of health instructions	0.070	0.004
		C47	Existence and continuous updating of environmental protection instructions	0.109	0.006

Table 1. Continued.

Principle	Weight	Component			
		Code	Description	Weight in Principle	Weight in HSE-RI
Awareness and risk perception	0.149	C48	Understanding safety training	0.100	0.015
		C49	Understanding health training	0.100	0.015
		C50	Understanding environmental protection training	0.100	0.015
		C51	Awareness from the safety considerations of career	0.100	0.015
		C52	Awareness from the health considerations of career	0.100	0.015
		C53	Awareness from the environmental considerations of career	0.100	0.015
		C54	Awareness from emergency response requirements	0.100	0.015
		C55	Awareness from safety requirements and hazards	0.100	0.015
		C56	Awareness from health requirements and hazards	0.100	0.015
		C57	Awareness from environmental requirements and hazards	0.100	0.015
Performance	0.144	C58	The role transparency (reasonable expectation from employees)	0.071	0.010
		C59	Having enough time to do the job	0.071	0.010
		C60	Complying with safety requirements	0.214	0.031
		C61	Complying with health requirements	0.214	0.031
		C62	Complying with environmental requirements	0.214	0.031
		C63	Follow the emergency response plan when accidents occur	0.214	0.031
Preparedness	0.144	C64	The organized and active review (before occurrence) of safety hazards	0.200	0.029
		C65	The organized and active review (before occurrence) of health hazards	0.200	0.029
		C66	The organized and active investigation (before occurrence) of environmental hazards	0.200	0.029
		C67	Existence of a written plan for dealing with emergencies	0.200	0.029
		C68	Providing adequate resources to deal with emergencies	0.200	0.029
Flexibility	0.055	C69	Providing adequate resources to deal with unexpected events	0.200	0.011
		C70	Full discretion in important actions and decisions in critical situations	0.200	0.011
		C71	The financial and technical ability to respond to unexpected changes and conditions	0.200	0.011
		C72	The organization ability to adapt to internal and external stressful conditions	0.200	0.011
		C73	The system ability to return to stable conditions in the event of a malfunction	0.200	0.011
Redundancy	0.017	C74	Determination of responsible person for replacement of personal protective equipment	0.200	0.003
		C75	Forecasting alternative person for active employees	0.400	0.007
		C76	Providing a sufficient number of machine spare parts	0.400	0.007

commitment), "encourage employees to stop working when there is a defect in environmental protection" (0.055, S14 related to the principle of top management commitment), and "follow the emergency response plan when accidents occur" (0.031, C63 related to the principle of performance). On the other hand, the five components with the lowest weight (all with a weight of 0.001 related to the principle of reporting and just culture) were "existence of a system for recording and reporting environmental hazards" (C25), "existence of a system for recording and reporting accidents and incidents" (C23), "existence of a system for recording and reporting health hazards" (C24), "possibility of consulting with a supervisor when there is a concern about work safety" (C20), and "possibility of consulting with a supervisor when there is a concern about health status", "the existence of a system for recording and reporting health hazards" (C21).

HSE resilience of the SWM system of Tehran

The HSE-RI scores of the SWM system of Tehran by demographic and occupational characteristics of the participants are provided in Table 2.

According to Table 2, the average HSE-RI scores of the SWM system were determined to be 63.8 for transfer and transport, 62.6 for processing and composting units, 61.9 for sanitary landfill site, and 62.9 for whole

Table 2. Assessment of HSE resilience in SWM system of Tehran by sector and demographic and occupational characteristics of the participants

Variable	Variable Levele	Frequency	Frequency Percent	HSE-RI Score		*P* value
				Average	SD	
Sector	Transfer and transport	114	37.9	63.8	5.9	0.139
	Processing and composting units	138	45.8	62.6	7.4	
	Sanitary landfill site	49	16.3	61.9	5.6	
Level of education	Diploma	282	93.7	62.8	6.5	0.711
	Bachelor	14	4.7	62.2	8.4	
	Master or PhD	5	1.7	63.8	4.2	
Residence	Native	107	35.5	63.5	7.2	0.258
	Non-native	194	64.5	62.6	6.2	
Age groups (year)	19-30	128	53.42	63.3	4.9	0.814
	31-40	116	54.38	62.6	8.5	
	41-50	51	94.16	62.5	5.1	
	51-60	6	2	61.3	7	
Job position	Administrator	15	5	63.2	8.6	0.074
	HSE officer	8	2.7	64.8	4.4	
	Supervisor	2	0.7	76.1	17.5	
	Installation and repair technician	36	12	62.2	9	
	Driver	51	16.9	63.5	5	
	Operational worker	189	62.8	62.6	6.1	
Marital status	Single	102	33.9	63.1	6.9	0.644
	Married	199	66.1	62.8	6.4	
Employment status	Permanent	1	0.3	88.5	-	0.001
	Temporary to permanent	119	39.5	63.0	6.3	
	Contractual	2	0.5	66.9	4.6	
	Other (daily, without contract)	179	59.5	62.7	6.5	
Work experience (year)	0-4	63.0	20.9	62.7	6.3	0.947
	5-9	55.0	18.3	63.5	4.9	
	10-14	68.0	22.6	62.4	5.8	
	15-19	57.0	18.9	62.9	9.6	
	20-29	51.0	16.9	63.3	4.6	
	>30	7.0	2.3	63.9	10.9	

the system. Among the demographic and occupational characteristics, only employment status had a significant effect on the HSE-RI score ($P<0.001$) and the index scores in different groups were as follows: 88.5 for permanent, 63.0 for temporary to permanent, 66.9 for contractual, and 62.7 for without contract. Figure 2 shows the qualitative description of the HSE-RI score in the SWM system of Tehran by sector. In all the sectors and the whole system, more than 60% of employees characterized the HSE resilience at the moderate level. The percentages of description of resilience status as good or excellent in transfer and transport, processing and composting units, sanitary landfill site, and whole the system were 36.0%, 28.2%, 22.4%, and 30.2%, respectively.

The scores of the HSE-RI components in the SWM system of Tehran are presented in Figure 2. According to Figure 2, the seven components with the highest HSE-RI score (76.0) in the SWM system of Tehran were "awareness of top management about the factors that threaten the activities of the organization" (C19, related to the principle of reporting and just culture), "existence of a system for recording and reporting accidents and incidents" (C23, related to the principle of reporting and just culture), "existence and continuous updating of safety instructions" (C45, related to the principle of learning culture), "understanding of safety training" (C48, related to the principle of awareness and risk perception), "awareness from the safety considerations of career" (C51, related to the principle of awareness and risk perception), "awareness from emergency response requirements" (C54, related to the principle of awareness and risk perception), and "awareness from safety requirements and hazards" (C55, related to the principle of awareness and risk perception). On the other hand, the five lowest HSE-RI scores of the

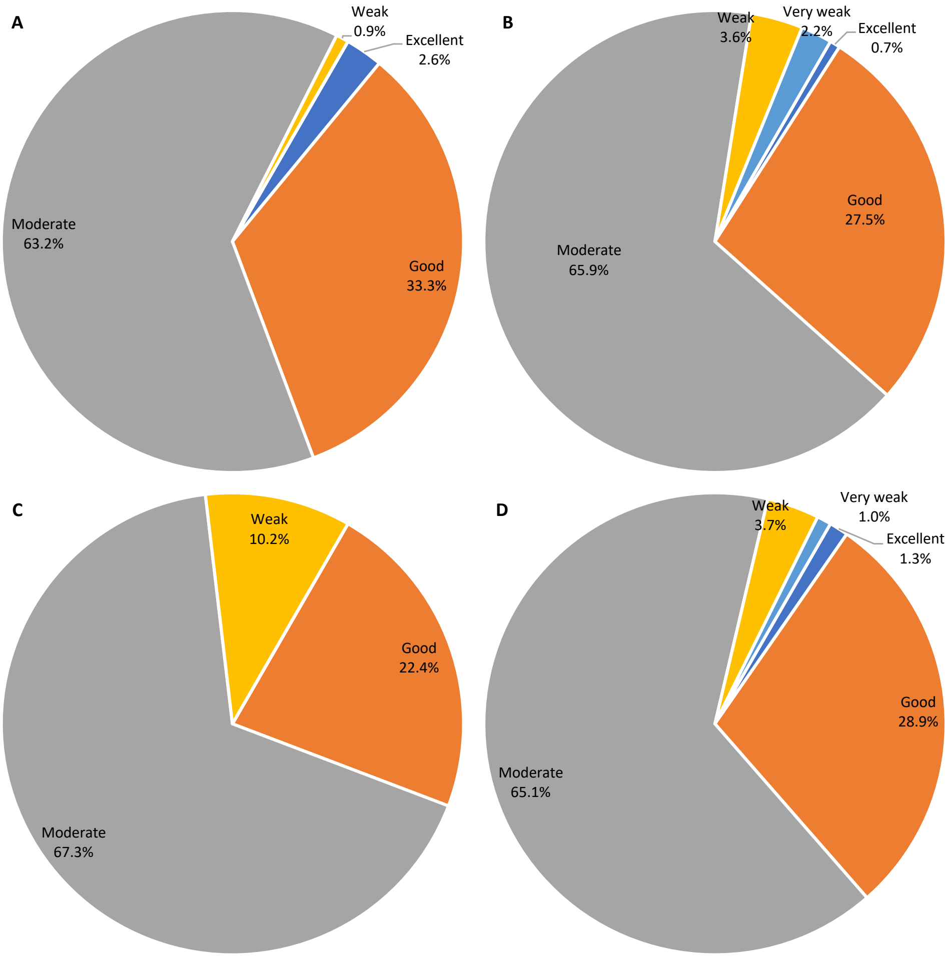

Figure 2. Qualitative description of HSE-RI score in different sectors of SWM system of Tehran: (A) transfer and transport, (B) processing and composting unit, (C) sanitary landfill site, and (D) the whole system

components were 26.6 for "influence of employees on the manager or supervisor decisions" (C32, related to the principle of reporting and just culture), 27.6 for "efforts to promote the HSE culture" (C41 related to the principle of learning culture), 27.9 for "participatory decision-making on HSE-related issues" (C33, related to the principle of reporting and just culture), 30.3 for "rewarding to the active employees in improving and promoting workplace health issues" (C30, related to the principle of reporting and just culture), and 30.4 for "rewarding to the active employees in improving and promoting workplace safety issues" (C29, related to the principle of the reporting and just culture).

The scores of HSE-RI principles of the SWM system of Tehran by sector is shown in Figure 3. According to Figure 3, the average score of each principle by sector was not significantly different. The highest and lowest average scores of the resilience principles in the whole SWM system were related to the principles of awareness and risk perception, and reporting and just culture to be 73.6 ± 8.2 and 45.1 ± 5.6, respectively.

Sensitivity analysis

The effect of removing each principle on the average score of the HSE-RI is shown in Figure 4. The effect of removing each principle in the average value of the HSE-RI was in the range of -3.8 to + 2.9. The results showed that none of the input principles had a very strong effect on the score of the resilience index and the index can reflect the contribution of all input principles. The principles with significant positive effects, including preparedness (+ 2.8), reporting and just culture (+ 1.1), and flexibility (+ 0.4) were worse than all the input principles, and their elimination rose the average value of the resilience index. In contrast, the principles with a significant negative effect, including top management commitment (-3.8) and awareness and risk perception (-1.9) were better than all the input principles and their elimination decreased the average value of the resilience index. The principles with a significant positive effect on the results of sensitivity analysis could be considered as the challenging aspects of resilience and most effective points for corrective measures. All the one-principle removed HSE-RIs were significantly correlated to the main index ($R^2 > 0.94$, $P < 0.002$); therefore, none of the input principles had a very strong effect on the resilience index and the HSE-RI could characterize the HSE resilience in the SWM system of Tehran based on the contribution of all the input principles.

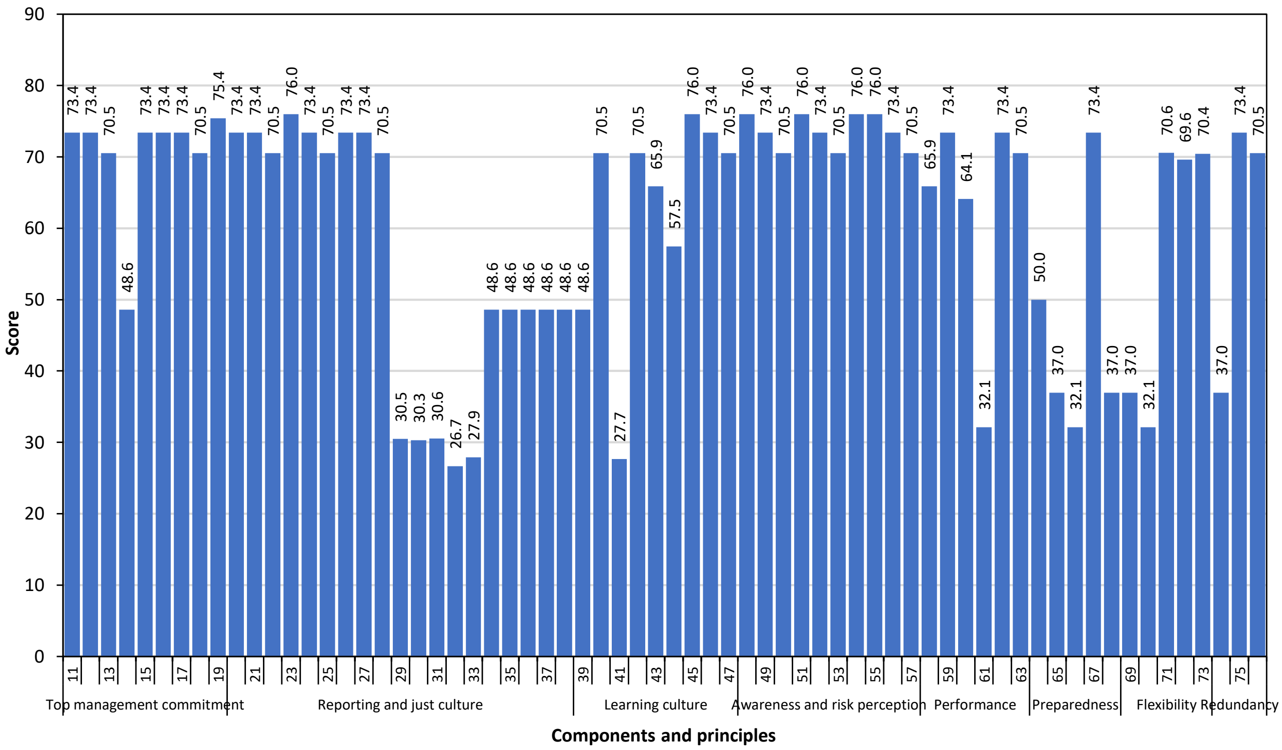

Figure 3. Scores of the HSE-RI components in the SWM system of Tehran

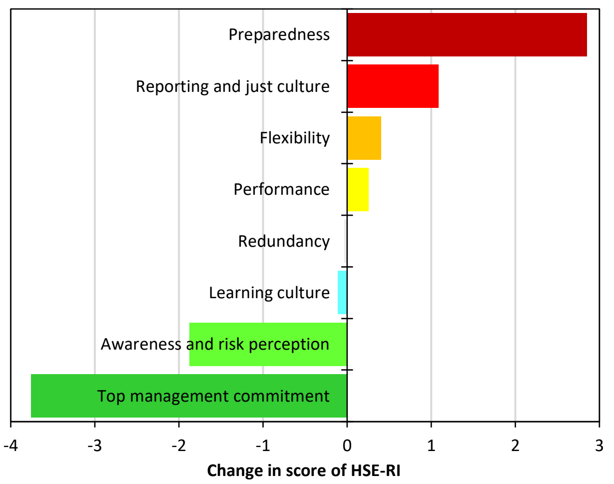

Figure 4. Effect of removing each principle on the average score of the HSE-RI

Discussion

The weighting results of HSE resilience principles in this study were consistent with the results of several studies (19,20,28). Azadeh et al (19) showed that the principles of reporting and just culture, top management commitment, and preparedness were the most important factors influencing resilience. Arassi et al (20) reported that management commitment and the organizational culture were the most important determinants of resilience in the operational units of the National Iranian Drilling Company of Khuzestan. They found the experienced workforce as the most important strength of the system resilience and the financial problems as the most important challenge of safety and resilience.

The high score of awareness and risk perception (first rank, 73.6 ± 8.2) could be due to continuous presence of HSE officers in the SWM system, continuous and daily training of safety, health, and environmental considerations to the employees, and relatively high work experience of the employees. The average score of top management commitment in the SWM system was in the second rank. The most important weakness of top management commitment in the HSE-RI of the SWM system was the component of encouraging employees to stop working when there was a loss in environmental conditions (48.6 ± 9.1). The average score of redundancy in the SWM system of Tehran was determined to be 65.0 ± 8.2 as shown in Figure 5.

The most important limitation of the redundancy principle was the absence of the responsible person for the replacement or inadequate distribution of personal protective equipment. This limitation was particularly evident during the COVID-19 pandemic and had a significant adverse effect on the performance of the HSE management system. The average score of learning culture principle in the whole waste management system of Tehran was 64.7 ± 9.0 as shown in Figure 5. The most important strength points in learning culture were holding health and safety retraining courses and existence and continuous updating health, safety, and environmental guidelines. The low score of preparedness in the SWM system of Tehran (45.9 ± 8.8, sixth rank) was due to the lack of the organized and active review of health and environmental hazards and inadequate resources to deal with emergencies. The lowest score of the HSE-RI

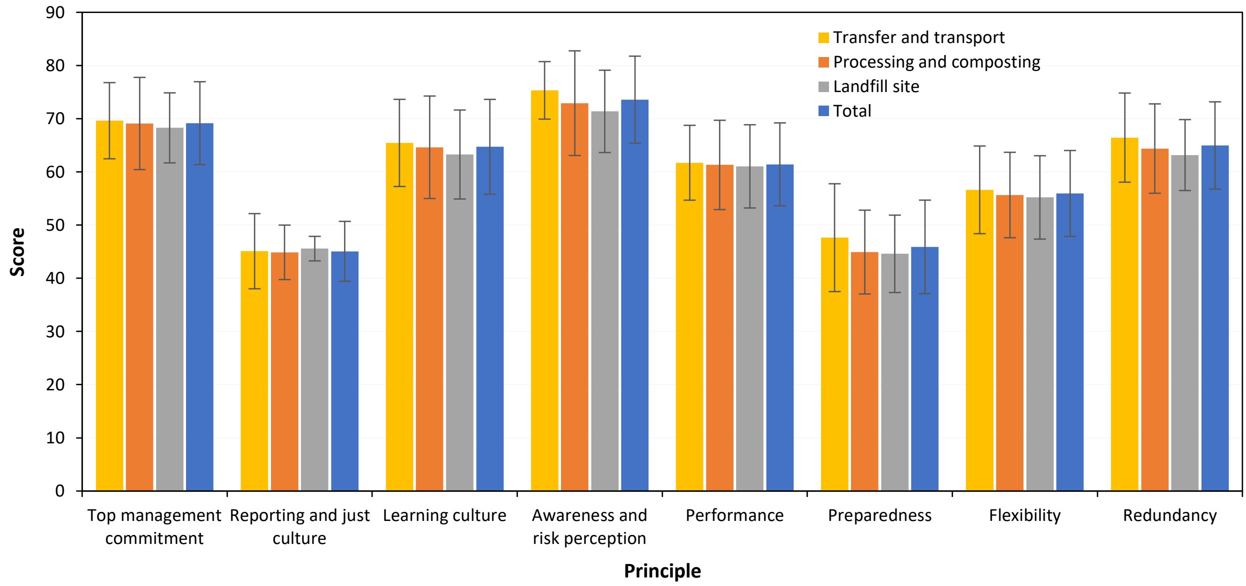

Figure 5. Scores of the HSE-RI principles in the SWM system of Tehran by sector

principles in the SWM system of Tehran was related to reporting and just culture to be 45.1 ± 5.1. In the reporting and just culture, the components with the lowest scores were "rewarding to the active employees in improving and promoting workplace health, safety and environment", "influence of employees on the manager or supervisor decisions", and "participatory decision-making on the HSE-related issues".

The high score of the principle of top management commitment was consistent with the results of several studies (25,29). Zarrin and Azadeh (30) in the study of influences of resilience on health, safety, environment, and ergonomics in a petrochemical industry determined the most effective principles to be top management commitment (0.827) on the environment, learning (0.792) on the health, preparedness (0.786) on the ergonomics, and awareness (0.776) on the safety. In the study of Rubio-Romero et al (25) on the occupational health and safety resilience in municipal SWM facilities, the highest weight and score of resilience were related to top management commitment. Orencio and Fujii (31) reported environmental resource management as the most important measure of resilience during disasters in coastal communities. In the study of Mohammadi and Teymouri (29), the highest score of resilience principles of health, safety, and environmental management system in the Zanjan Zinc Industrial Town was related to leadership and top management commitment. Battaglia et al (32) in the study of health, safety, and environmental management in municipal SWM in Italy indicated that training, staff involvement, and operational activities were the most developed aspects, while occupational health and safety policy and performance measurements needed further improvement.

The values of the HSE-RI of the SWM system of Tehran were comparable with those reported by Rubio-Romero et al (25). They reported that the overal score of occupational health and safety resilience in a solid waste collection and delivery service in the city of Málaga, Spain, was determined to be 68.4 (in the scale of 0 to 100). They also determined the descending order of the resilience principles in the solid waste collection and delivery service to be top management commitment (73.63), preparedness (72.57), awareness and opacity (69.37), culture of learning (65.73), just culture (65.70), and flexibility (62.73) (25). In the study of prioritizing HSE hazards in the SWM facilities of Tehran by Moloudi et al (26), the total number of identified HSE hazards was 485, of which about 8.2% were assessed to be high-risk hazards. The leading HSE hazards in the SWM facilities of Tehran by sector were determined to be exposure to bioaerosol in transfer and transport, exposure to bioaerosols and odor/volatile organic compounds in material recovery and composting facilities, and leachate spills in landfill sites. The observed high-risk hazards could be partially controlled with reinforcement of the HSE resilience in the SWM facilities of Tehran.

The Delphi technique could increase the reliability of the HSE-RI. Weighting the final principles and components of the HSE-RI using the AHP could successfully reflect the disproportionate effects of the input parameters in the integrated index (22,25). A thorough balance amongst HSE was considered in the HSE-RI, whereas in the previous studies safety aspects received more attention in resilience assessment. The other advantage of this study was conducting a comprehensive assessment of HSE resilience in the SWM facilities of Tehran. As the most important limitation of this study, the HSE resilience of the SWM facilities of Tehran was only assessed based on the staff feedback. In the future studies, the staff feedback for the assessment of HSE resilience can be supplemented with field audits and reviewing documents.

Conclusion

The resilience status of the SWM system of Tehran and all the three sectors of transfer and transport, processing and composting units, and sanitary landfill site were assessed to be at the moderate level. The weights of the HSE-RI principles were in the following order: top management commitment > awareness and risk perception > performance > preparedness > reporting and just culture > learning culture > flexibility > redundancy. The highest and lowest average scores of the resilience principles in the whole SWM system were related to the principles of awareness and risk perception, and reporting and just culture, respectively. The results of this study showed that the status of HSE-RI in the waste management system of Tehran was not at the desired level and this situation could cause a high level of HSE risks. Reinforcement of the HSE resilience in the SWM system of Tehran could be more efficiently achieved with an especial emphasis on the principles of top management commitment (with the highest weight), reporting and just culture and preparedness (with the lowest scores).

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Authors' contribution

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Competing 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.

Ethical issues

This study was approved by the Research Ethics Committee of School of Public Health and Neuroscience Research Center, Shahid Beheshti University of Medical Sciences in accordance with the declaration of Helsinki for human studies of the World Medical Association (Ethical code: IR.SBMU.PHNS.REC.1399.053). All the ethical guidelines and safety procedures were considered during the experimental period.

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