2008-5435/14/63-66-77
INTERNATIONAL JOURNAL OF OCCUPATIONAL HYGIENE

IJOH 9: 66-77, 2017

ORIGINAL ARTICLE

A Fuzzy Analytic Hierarchy Process Approach to Identify and Prioritize Environmental Performance Indicators in Hospitals

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Received February 27, 2017; Revised March 11, 2017; Accepted May 12, 2017

This paper is available on-line at *http://ijoh.tums.ac.ir*

ABSTRACT

Being threatened by various facilities in a city, modern urban environments have become extremely vulnerable and fragile. Hospitals are among potentially high-risk facilities. Environmental awareness is relatively lacking in the health sector with few organizations measuring their performance. Therefore, the issue is exceedingly important. This study aimed to identify and prioritize factors that influence environmental performance in hospitals. To identify factors that influence environmental performance in hospitals, a comprehensive review of literature was performed to compile a list of criteria, sub-criteria, and indicators of environmental performance in healthcare centers. The list was then adjusted by experts in the field using the fuzzy Delphi method and the factors were prioritized using fuzzy analytical hierarchy process. In order to verify the results, a fuzzy technique was also applied to determine the order of preference by similarity to ideal solution. Therefore to verify the weights and priorities assigned to the factors influencing environmental performance, the factors were once again rated by experts based on the criteria of specificity, measurability, availability, being realistic, and time-related. Six criteria, 22 sub-criteria, and 48 indicators were identified and prioritized. Furthermore, Fuzzy AHP and Fuzzy TOPSIS resulted in the same prioritization of the factors. Therefore, the results obtained from Fuzzy AHP are acceptable. Using appropriate indicators together with appropriate techniques can serve to improve the environmental performance in health care centers. The obtained results showed that the FAHP method could be used for prioritizing environmental performance factors in hospitals successfully.

KEYWORDS: *Environmental indicators, Delphi method, FAHP, FTOPSIS, Hospital*

INTRODUCTION

Identifying, rating, and prioritizing factors affecting environmental performance allow environmentally conscious managers to effectively lessen and/or prevent adverse environmental effects caused by inadequate performance. Because of increased environmental pressures associated with the activities of organizations, environmental and economic efforts are now equally important. Thus, it is critical to promote efforts such as optimizing the consumption of energy and resources, waste

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reduction, making processes less detrimental to the environment, and preventing pollution. Furthermore, organizations are expected to make use of an appropriate environmental management system (EMS) in their business. It is necessary to accurately measure and evaluate the impact of organizational activities on the environment and the outcomes of environmental efforts (i.e. environmental performance). In fact, the environmental performance (EP) is defined as "measurable results of an organization's management of its environmental aspects" [1]. Hence, appropriate criteria are needed to measure and assess environmental performance. Therefore, environmental performance indicators are becoming increasingly important at the company level to measure and assess environmental performance [2-3]. In other words, indicators are defined as the "specific expression that provides information about an organization's environmental performance" [4].

The health sector is a major part of the economy in any country. The activities of the sector are associated with environmental impacts [5]. Thus, as in any complex organization, healthcare centers require strong and effective management [6]. As long as technology continues to advance, resources are consumed, waste is generated, and buildings are built and used globally, the health sector is a main cause of pollution and contributes to the indirect destruction of the environment. By consuming resources and generating waste while providing services, healthcare centers substantially affect the environment [7]. Therefore, they are forced to face formidable challenges in preserving the environment, adding to the significance of managing environmental performance in healthcare centers. However, environmental awareness is relatively lacking in the health sector with few organizations measuring their performance [5]. Furthermore, the ability to manage environmental performance in healthcare centers is restricted by obscure aspects such as extensive processes and lack of ways to quantify factors that influence performance. To the best of our knowledge, factors that affect the environment remain to be systematically identified and prioritized.

Environmental performance must be measured in order to preserve the environment [8]. In fact, multidimensional structural performance is composed of several components that help the overall performance of the healthcare center [9]. Thus, assessing environmental performance is the process of facilitating managerial decisions regarding environmental performance through relevant criteria, data collection and analysis, comparison of information with standards, reporting, regular reviews, and continuous improvement [10]. Defining and identifying accurate and practical criteria is the single most important step in the evaluation process [11]. Therefore, environmental performance indicators must reflect operational status, environmental conditions, environmental policies, stakeholder needs, and the nature of the business in the organization. These criteria need to provide information that is helpful in making decisions regarding environmental issues. Besides, comparison of performance must be possible.

These indicators should form part of all monitoring and enforcement regimes, as a tool to simplify, quantify and communicate environmental data [12].

Overall, environmental performance indicators can be used to regularly assess and report on environmental performance in organizations, business units, and departments as well as that of employees. In fact, the indicators measure environmental targets [13]. By measuring environmental performance indicators, meaningful objectives and strategies can be defined. Moreover, environmental performance indicators are able to represent succinctly vast amounts of data [14].

Due to the relative evolving knowledge about environment health interactions [15] and lack of knowledge about environmental issues in the health sector (e.g. lack of awareness about the health hazards related to health-care waste) [16] and also in case of developing countries such as Iran, healthcare operations face major challenges including high costs of health care services, limited productive resources, conditions in the crisis management, inadequate infrastructure and structure (e.g. access to clean water, electricity), it is necessary to facilitate performance measurement in this sector, by selecting a set of performance indicators [5, 17].

A number of studies have been performed to identify environmental criteria including a set of performance indicators proposed by Japan's Ministry of the Environment [2]. Moreover, several performance indicators were established in a study on energy consumption and management in Farabi Ophthalmology Hospital in Tehran [18]. A number of factors that influence environmental performance in hospitals were identified in study titled "The Measurement of Environmental Performance in Hospitals: A Framework and Process" [19]. A microbiological evaluation of the quality of air in various parts of a hospital led to the identification of air quality indicators in hospitals [20]. A waste management model for hospitals was proposed which determined the interactions between the factors in a system using Stella [21]. The risks associated with various types of medications in hospital wastewater were studied in general and psychiatric hospitals in Sweden [22].

Environmental sustainability in hospitals – a systematic review a research agenda is another topic studied in 2014 [23]. The criteria related to the sustainability's triple bottom line, including other criteria, have been identified for the selection of a sustainable location of healthcare waste disposal facility in another research studied in 2016 [24]. The other study was about material consumption in the healthcare sector. This research that concluded that considerable reductions of the impact on climate change could be achieved by implementing good housekeeping in working routines and by addressing green purchasing to prevent inefficient consumption patterns [25].

The aim of this study was to identify and prioritize factors that influence environmental performance in hospitals of Tehran, Iran.

MATERIALS AND METHODS

This research was carried out in hospitals in Tehran, Iran during 2015- 2016, including two main stages detailed as follows:

Stage 1: Identifying the criteria, sub-criteria, and indicators of environmental performance in healthcare centers using the fuzzy Delphi method [26], [27].

Stage 2: Prioritizing and assigning weights to the criteria, sub-criteria, and indicators using the analytical hierarchy process (AHP) before verifying the results using fuzzy TOPSIS (Fig. 1).

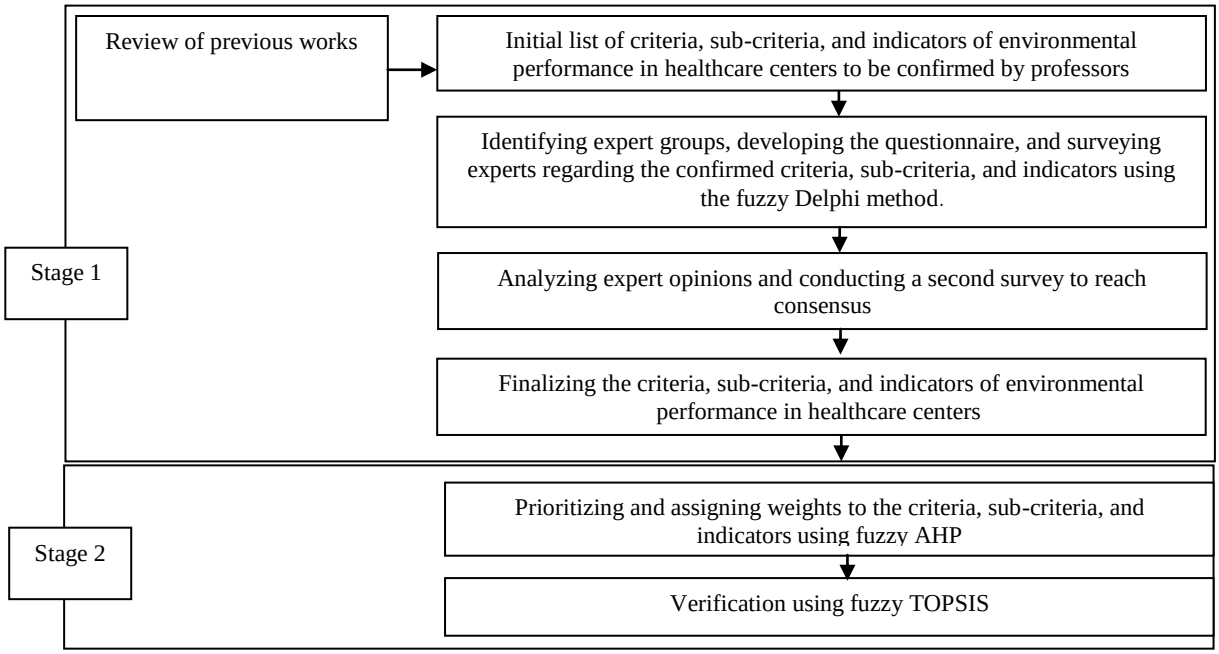

***Fig*. 1.** The steps involved in the process of this study

As shown in *Fig*. 1, subsequent to reviewing previous works, a list of factors that influence environmental performance in healthcare centers is confirmed by university professors. Next, necessary adjustments are made before experts select the significant factors. Finally, fuzzy Delphi is performed as in the following.

1.1. Fuzzy Delphi: The fuzzy Delphi method was leveraged to identify the factors influencing environmental performance in healthcare centers. In this method, experts express their opinions in the form of Linguistic variables; mean scores are calculated and, for each opinion, the deviation from the mean is determined. The experts are encouraged to revise their judgments upon receiving these pieces of information. In the next round, each member of the panel provides a new or revised opinion based on the results of the previous round. The process continues until average fuzzy numbers converge to stable values [28]. A flowchart of the fuzzy Delphi method is depicted in *Fig*. 2.

The first step in the fuzzy Delphi method concerns the selection of experts. In this study, an expert is defined as an individual with at least five years of relevant work experience and a bachelor's degree who graduated at least three years prior to conducting the study. Furthermore, in order to be deemed qualified; the experts must have extensive knowledge of processes and services in hospitals. Thus, the statistical population of the study includes 25 experts. Once the panel was chosen, a questionnaire was developed to discover expert opinions about the criteria, sub-criteria, and indicators of environmental performance in healthcare centers. Answers were given using verbal variables defined as triangular fuzzy numbers (Table 1).

Published online: June 20, 2017

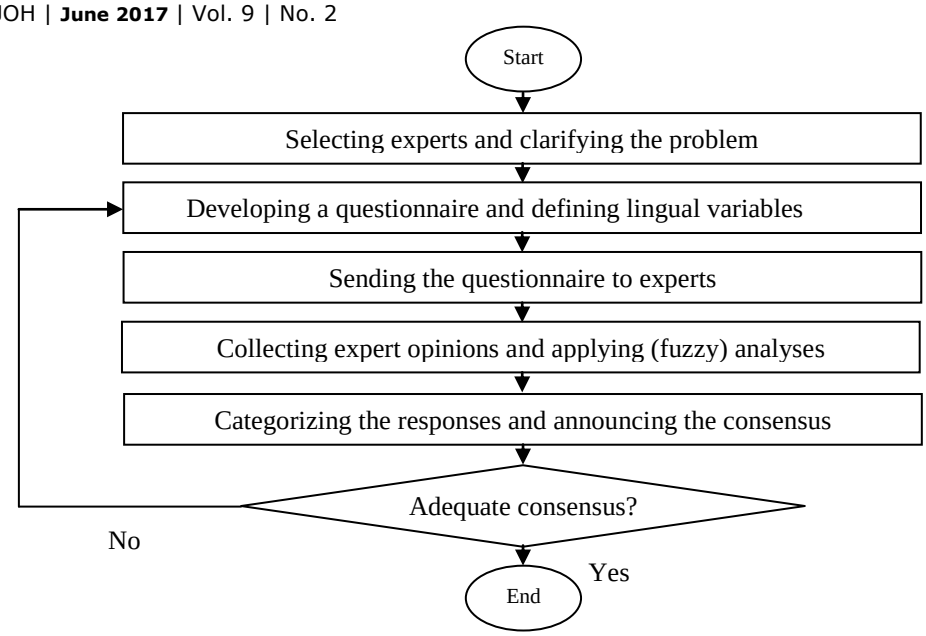

***Fig.* 2.** A flowchart of the fuzzy Delphi method in the present study

Table 1. The definition of scales and crisp numbers [29-30]

Linguistic term	Triangular fuzzy number			Crisp number
	M	α	β	
Very low	0.0	0.0	0.3	0.075
Low	0.3	0.3	0.2	0.275
Medium	0.5	0.3	0.3	0.500
High	0.7	0.2	0.3	0.725
Very high	1.0	0.3	0.0	0.925

The next step was to distribute the questionnaire and analyze the obtained results. The step involved several rounds in reaching an adequate consensus.

1.1.1. Round one : In this round, the criteria, sub-criteria, and indicators of performance were introduced and panel members expressed the extent to which they agreed with each item (Table 1). A summary of expert judgments was generated. For each criterion, sub-criterion, and indicator, an average score was obtained and the differences for each expert's opinion were calculated. This information was communicated to the experts. In addition to close-ended items, several open-ended questions were included in determining expert opinions. As a result, two sub-criteria (waste recycling and soil pollution) and two indicators (Soil pollution monitoring and soil pollution control activities) were added after the first round.

1.1.2. Round two: Subsequent to applying necessary modifications to the criteria and sub-criteria, the second version of the questionnaire was created and sent to each member of the panel, along with his/her previous judgments and the extent of deviation from the mean. The answers were analyzed in the same manner as round one. For each item, if the difference between the results from the two rounds was smaller than a predetermined threshold, the polling process stopped [28]. Thus, excluding the indicators of environmental participation, rewards, acknowledgment, and green plates, environmental performance of contractors and the percentage of reduction in electricity consumption, panel members reached a consensus on the environment. Moreover, in this round, the experts agreed on all the items except the number of floors/buildings and the number of wards. These indicators were eliminated since they had very low scores.

1.1.3. Round three: In this round, in addition to making the required adjustments in the components and criteria, a third version of the questionnaire was created and (as in the previous round) sent to each member of the panel, along with his/her previous judgment and the extent of deviation from the mean. However, the third round only concerned the three remaining indicators. The differences between expert opinions in rounds two and three were also calculated. The results indicated a very small difference, which resulted in stopping the polling process. As depicted in Fig. 1, the first stage is followed by the application of the Fuzzy AHP in order to prioritize and assign weight to the final criteria, sub-criteria, and indicators. The procedure is briefly explained as follows:

1.2. Fuzzy analytical hierarchy process: The original AHP is often criticized for not being able to handle the inherent uncertainty of real-world situations and lacking sufficient accuracy in pairwise comparisons [31]. To overcome this problem, FAHP was proposed [32].

In this paper, the FAHP approach is employed which involves the following steps [33]:

Step 1: Creating the hierarchy

Step 2: Defining the fuzzy numbers for pairwise comparison

Step 3: Constructing the pairwise comparison matrix using the fuzzy numbers

Step 4: Calculating S_i for each row of the pairwise comparison matrix

Step 5: Calculating the largeness degree for each S_i

Step 6: Calculating the weights in the pairwise comparison matrix.

Step 7: Calculating the final weight vector

In this paper, the necessary steps were taken to prioritize and assign weights to the final criteria, sub-criteria, and indicators using the algorithm in *Fig*. 3 and based on FAHP (Chang's extent analysis).

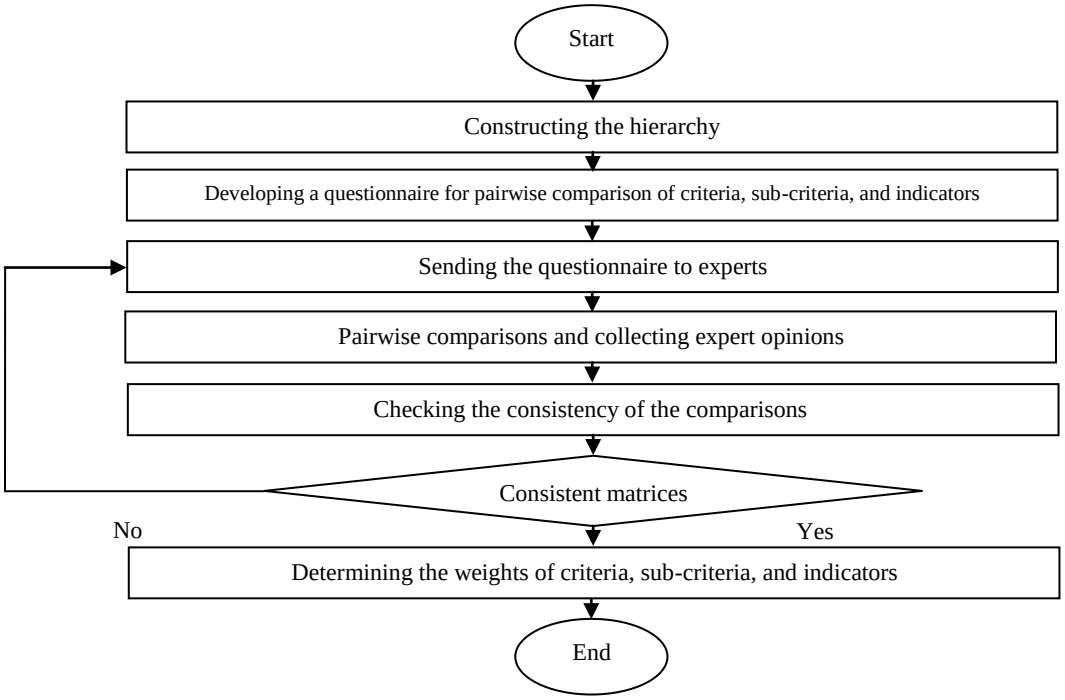

***Fig*. 3.** A flowchart of the FAHP algorithm

The first step in FAHP is to construct the hierarchy composed of four levels in this study. The first level is the objective (i.e. determining the factors that influence environmental performance in healthcare centers); criteria and sub-criteria comprise the second and third levels, respectively; finally, the fourth level relates to indicators that influence environmental performance in healthcare centers.

The hierarchical diagram in Fig. 4 illustrates how the criteria, sub-criteria, and indicators relate to one another (note that, given a large number of indicators, they are shown in Table 4.

Published online: June 20, 2017

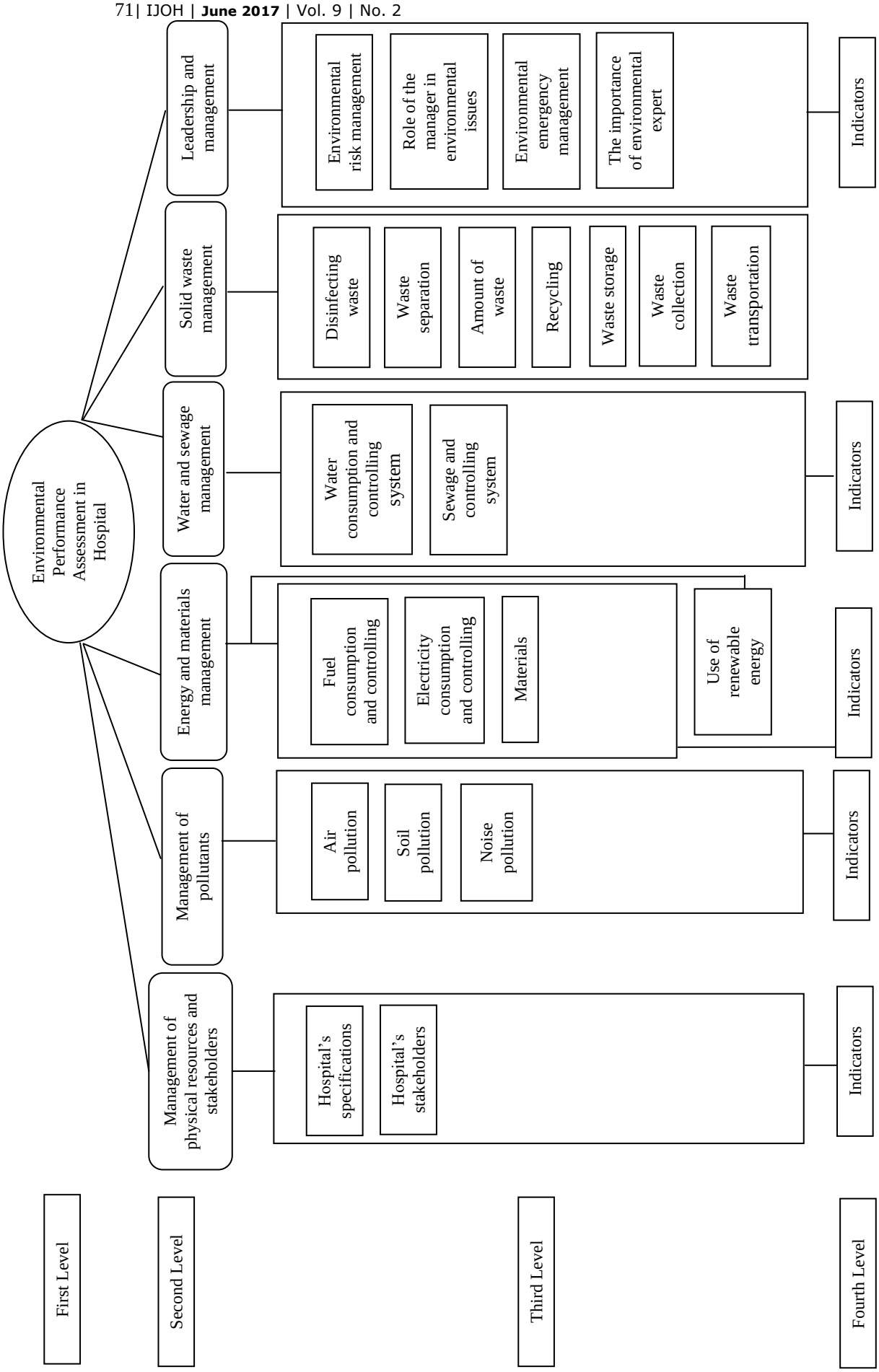

Fig. 4. The hierarchy of the study

Published online: June 20, 2017

Next, in order to determine the significance and priority of the criteria, sub-criteria, and indicators, panel members were given a questionnaire to perform pairwise comparisons in the form of the verbal variables in Table 2.

Table 2. Definition of the fuzzy numbers for the pairwise comparison of the criteria, sub-criteria, and indicators [34]

ferences (Linguistic)	Fuzzy Number	Scale of Fuzzy Number		
		l	m	u
Extremely preferred, desired, or important	9	8.0	9.0	10
Very strongly preferred, desired or important	8	7.0	8.0	9.0
Strongly preferred, desired or important	7	6.0	7.0	8.0
Moderately preferred, desired or important	6	5.0	6.0	7.0
Sufficiently preferred, desired or important	5	4.0	5.0	6.0
Preferred, desired or important	4	3.0	4.0	5.0
Slightly preferred, desired or important	3	2.0	3.0	4.0
Hardly preferred, desired or important	2	1.0	2.0	3.0
Equally preferred, desired or important	1	1.0	1.0	1.0

After collecting the pairwise comparison matrices, a geometrical average was calculated to unify expert opinions. However, before performing the other steps, the matrices needed to be checked for consistency to avoid generating incorrect results. This was performed using the method proposed [35]. If the Consistency Ratio (CR) was greater than 0.1, the expert making the judgment was asked to reconsider his/her comparisons. All of the experts were given equal importance.

Subsequent to prioritizing the factors that influence environmental performance in healthcare centers, the results needed to be verified. This was done using fuzzy TOPSIS.

1.3. Fuzzy TOPSIS: TOPSIS is a useful technique in multi-criteria decision-making for handling real-world problems [36]. The approach defines similarity as proximity to positive ideal or distance from the negative ideal solution. The alternative with the smallest distance from the positive idea is chosen [37]. However, decision-makers often have difficulty assigning exact values to various criteria. Therefore, fuzzy numbers are preferred over crisp values. In this paper, fuzzy TOPSIS is employed to verify the results according to mathematical concepts proposed. The procedure involves the following steps [38-39]:

Step 1: Constructing the decision matrix
Step 2: Determining criteria weights
Step 3: Normalize the fuzzy decision matrix:
Step 4: Creating the weighted fuzzy decision matrix
Step 5: Identifying the Fuzzy Positive Ideal Solution (FPIS; A*) and the Fuzzy Negative Ideal Solution (FNIS, A^-):
Step 6: Calculating the distance from the FPIS and FNIS
Step 7: Calculating the similarity index
Step 8: Ranking the alternatives

The alternatives are ranked according to similarity and those having the greatest similarity are given the highest priority.

In this paper, in order to verify the weights and priorities assigned to the factors influencing environmental performance, the factors were once again rated by experts based on the criteria of specific, measurable, attainable, realistic, time-related (SMART) in the form of Table 3 [40]. A second ranking of the factors was obtained using TOPSIS.

Table 3. Definition of fuzzy numbers for rating the criteria, sub-criteria, and indicators

Verbal Judgment or Preference	Triangular Fuzzy Number		
	l	m	u
Extremely Preferred	4.00	5.00	6.00
Very Strongly Preferred	3.00	4.00	5.00
Strongly Preferred	2.00	3.00	4.00
Moderately Preferred	1.00	2.00	3.00
Equally Preferred	0.00	1.00	2.00

RESULTS

Based on the model of the study, the criteria, sub-criteria, and indicators of environmental performance in healthcare centers were identified through desk research and expert opinions using the fuzzy Delphi method resulting in a total of 6 criteria, 22 sub-criteria, and 48 indicators (Table 4). Furthermore, based on Table 2 (verbal variables) and Chang's extended method, the pairwise comparisons and the weights assigned to the criteria, sub-criteria, and indicators of factors influencing environmental performance in healthcare centers are shown in Table 4. Furthermore, priorities of the criteria influencing environmental performance in medical centers are calculated using Fuzzy AHP, as depicted in Fig. 5.

Published online: June 20, 2017

Table 4. PART 1. Factors influencing environmental performance in healthcare centers and the normalized weights

Criteria	Normalized weight	Sub-criteria	Normalized weight	Index	Normalized weight
Solid waste management	0.30	Disinfecting waste	0.28	-	-
		Waste separation	0.18	-	-
		Amount of waste	0.17	-	-
		Recycling	0.16	-	-
		Waste storage	0.08	-	-
		Waste collection	0.07	-	-
		Waste transportation	0.06	-	-
Water and sewage management	0.27	Water consumption and controlling system	0.50	Reduction of water consumption per capita (%)	0.45
				Mechanisms to decrease water consumption	0.38
				Non-drinking water resources	0.17
		Sewage and controlling system	0.50	Amount of sewage	0.31
				Amount of sewage treatment (%)	0.29
				Effluent monitoring	0.17
				Type of sewage treatment system	0.12
				Fate of treated wastewater	0.12
Management of pollutants	0.21	Air pollution	0.53	Air emission monitoring	0.47
				Air pollution control activities	0.32
				Indoor air quality monitoring	0.21
		Soil pollution	0.27	Soil contamination control activities	0.50
				Soil pollution monitoring	0.50
		Noise pollution	0.20	Monitoring environmental noise pollution	0.50
				Noise control activities	0.50
Energy and materials management	0.11	Electricity consumption and controlling	0.30	Reduction of electricity consumption (%)	0.50
				Mechanisms to control electricity consumption	0.50
		Fuel consumption and controlling	0.30	Reduction of fuel consumption per capita (%)	0.28
				Control mechanisms for fuel consumption	0.27
				Types of heating and cooling system	0.21
				Types of corporate vehicle	0.17
				Personnel transportation system	0.07
		Materials	0.23	Reduction of paper consumption per capita (%)	0.73
				Use of chemicals (Pesticides, Disinfectants, Detergents, …)	0.27
		Use of renewable energy	0.17	-	-

Published online: June 20, 2017

Table 4. PART 2. Factors influencing environmental performance in healthcare centers and the normalized weight

Criteria	Normalized weight	Sub-criteria	Normalized weight	Index	Normalized weight
Leadership and management	0.08	Environmental risk management	0.57	Environmental management system certification	0.52
				An approach to identifying, assessment and reduction of environmental impacts	0.48
		Role of the manager in environmental issues	0.20	Financial resources assigned to environmental issues (%)	0.28
				Objectives and action plan on environmental issues	0.26
				Employee environmental training (%)	0.14
				Environmental corrective and preventive actions approved at management review meetings (%)	0.14
				Resolve environmental complaints (%)	0.12
				Environmental participation, rewards, acknowledgment, and green plates	0.06
		Environmental emergency management	0.14	Number of environmental maneuvers	0.35
				Preparation for the environmental emergencies	0.27
				Implemented preventive and corrective actions by the non-compliance observed in maneuvers	0.23
				Implementation of corrective actions resulting from an environmental emergency response	0.15
Management of physical resources and stakeholders	0.03	The importance of environmental expert	0.09	Experience of environmental expert	0.43
				Environmental unit in the organizational structure of the hospital	0.30
				Environmental expert degree	0.27
		Hospital's specifications	0.50	Infrastructure (m^2)	0.24
				Maintenance system	0.22
				Types of windows	0.20
				Age of hospital	0.17
				Green areas (%)	0.17
		Hospital's stakeholders	0.50	Number of admitted patients	0.27
				Employee's environmental performance	0.26
				Number of outpatients	0.25
				Environmental performance of contractors	0.21

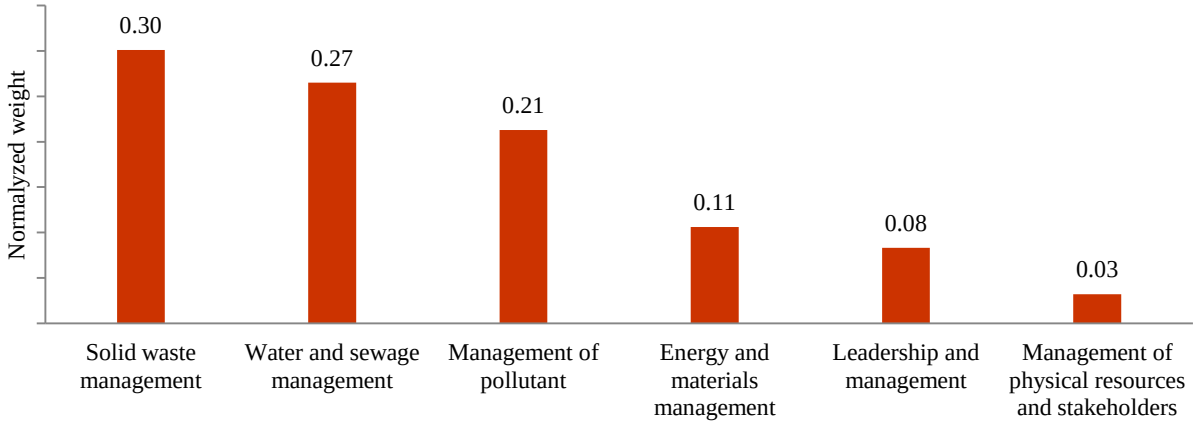

***Fig*. 5.** Final ranking of criteria using FAHP

A comparison of the results obtained by performing the fuzzy TOPSIS and fuzzy AHP for the purpose of verification can be seen in Table 5.

Table 5. Comparison of the criteria influencing environmental performance using fuzzy TOPSIS and FAHP

Published online: June 20, 2017

Criteria	Ranking based on FAHP	Ranking based on FTOPSIS	Difference (%)
Solid waste management	1	1	0%
Water and sewage management	2	2	
Management of pollutants	3	3	
Energy and materials management	4	4	
Leadership and management	5	5	
Management of physical resources and stakeholders	6	6	

DISCUSSION

The objective of this study was to identify and prioritize factors that influence environmental performance in hospitals.

Our findings showed that, among the criteria of environmental performance in healthcare centers, solid waste management had the highest weight. In a study entitled "Going toward green hospital by sustainable healthcare waste management: segregation, treatment and safe disposal", the waste generated by treatment activities have been associated with various infections and other harms [41]. Consistent with our results, this suggests that waste management is pivotal in healthcare centers.

Moreover, wastewater management was found to be the second most important criterion to affect environmental performance in hospitals. Prior studies also confirm the significance of the criterion [42].

Importantly, medical centers are unfit to identify systematically the factors that influence their environmental performance. This in turn adversely affects environmental management. At the heart of this phenomenon, senior executives often perceive very little value in environmental management, which manifests in their reluctance to invest in the area [43], [44].

Furthermore, this study focused on the priorities of the criteria, sub-criteria, and indicators affecting environmental performance in medical centers. For instance, waste management and management of physical resources and stakeholders were found to have the highest and lowest priorities, respectively. However, the criteria are merely mentioned without being ranked [45].

Leadership and management include fifteen indicators while solid waste management only has seven sub-criteria. With respect to water and sewage management, eight indicators are identified. Energy and materials management has nine indicators. Management of pollutant includes seven indicators. Finally, management of physical resources and stakeholders has nine indicators.

However, the impact of criteria such as supplying of financial resources, establishment of environmental structure like executive team, measurement levels of energy use, water consumption, waste stream, etc. are known as effective factors on Environmental Sustainability in Hospitals. This is in line with our results [43].

Furthermore, FAHP and fuzzy TOPSIS resulted in the same prioritization of the factors. Therefore, the results obtained from FAHP are acceptable.

The most important limitation of this study was lack of consensus among the few specialists we could find.

CONCLUSION

Our findings revealed a fundamental need to assess environmental performance in hospitals. By taking advantage of appropriate techniques and performance criteria, this assessment may have a profound impact on environmental performance in medical centers.

The criteria, sub-criteria, and indicators of environmental performance in healthcare centers were identified through desk research and expert opinions using the fuzzy Delphi method resulting in a total of 6 criteria, 22 sub-criteria, and 48 indicators. The inherent uncertainty in some of the criteria justified taking a fuzzy approach as the basis of the method. The significance of the different criteria, sub-criteria, and indicators was determined using expert opinions and FAHP based on pairwise comparisons. Taking advantage of Chang's method to prioritize and assign weights to the criteria, sub-criteria, and indicators, the results were verified using fuzzy TOPSIS.

Future studies can use other multi-criteria decision-making methods to verify our results. Moreover, a model to determine the environmental performance of health centers based on established criteria also recommended.

ACKNOWLEDGEMENTS

The authors declare that there is no conflict of interests.

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Published online: June 20, 2017