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A FUZZY MULTI-CRITERIA DECISION MAKING APPROACH FOR EVALUATING THE HEALTH-CARE WASTE TREATMENT ALTERNATIVES

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Abstract

Hierarchical distance-based fuzzy multi-criteria group decision making (DBF–MCDM) was applied to evaluate the health-care waste (HCW) treatment alternatives for Qom hospitals. A list of aspects consisting of 6 criteria and 21 sub-criteria were evaluated based on a linguistic term set by five decision-makers. Also, four HCW treatment alternatives including "incineration", "steam sterilization", "chemical disinfection" and "controlled landfill" were evaluated according to these aspects. Data were aggregated and normalized to obtain Performance Ratings of Alternatives (PRAs). Then, the PRAs were aggregated again to achieve the Aggregate Performance Ratings (APRs). After renormalization, the weighted distances (WDs) from ideal solution (D_i^*) and anti-ideal solution (D_i^-) were calculated. Finally, the proximity of each alternative to the ideal solution (Ω_i^*) was computed. The alternatives were ranked according to the magnitude of (Ω_i^*) values. Results demonstrated that "controlled landfill" was the most appropriate alternative for the HCW treatment of Qom hospitals and "steam sterilization" was the second acceptable treatment option. A novel configuration of criteria and sub-criteria was proposed based on the public health and occupational health risks. The criterion "Occupational Health" was added to the list of criteria to distinguish the health risks on public and those related to the healthcare waste management workers. Also, a new concept of "land requirement" was presented. The limitations of high-tech alternatives were also considered according to the level of dependency on overseas.

Key words: fuzzy logic, health-care waste, hospital, MCDM, treatment alternative

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1. Introduction

Health-care waste (HCW) comprises all types of wastes generated by hospitals, health-care facilities, research centers and medical laboratories (Prüss et al., 1999). Inadequate treatment and inappropriate final disposal of HCW can endanger public health and the environment. Furthermore, improperly managed HCW is the main cause of intra-hospital infections and may cause occupational health risks to the workers involved in the management of the wastes. Different methods such as combustion, autoclave, chemical sterilization, microwave disinfection and land disposal are widely applied as HCW treatment systems (Diaz et al., 2005). The selection of an appropriate HCW treatment method is affected by a numbers of criteria,

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which covers the economic, environmental, public health, and technical aspects. Some of the aspects are objective and measurable, while the others may be qualitative and hard for measurement (Baas and Kwakernaak, 1977). There are various decision making tools such as AHP (Brent et al., 2007; Chen et al., 2017), MCDA (Achillas et al., 2013), MCDM (Dursun et al., 2011b), and CAM (Hung et al., 2007), to evaluate the alternatives by considering the appropriate aspects for treatment of HCW. Multi-criteria decision-making (MCDM) is an effective tool in ranking of the potential alternatives. Studies revealed that more objective and transparent decision making can be made through using multiple criteria analysis (Chung and Poon, 1996; Nouri et al., 2016).

Human judgments are often not clear and have a degree of ambiguity. In many cases, crisp data are not adequate to describe the human-related decision problems (Chen and Chiou, 1999; Cheng et al., 2002). Consequently, it may not be suitable to identify these judgments by certain values. A reasonable way is to apply the linguistic terms for modeling the human decisions (Carlsson and Fullér, 2000). Thus, fuzzy MCDM approaches have recently been used in waste management. The main target of fuzzy MCDM models is to combine the assessments that have been expressed by decision makers. These assessments are the linguistic terms to evaluate both the criteria and alternatives (Chang et al., 2008; Gnoni et al., 2017).

The appropriate determination of judgment criteria has principal influence on final alternative selection. When an enormous number of performance attributes are available to be judged in a process of evaluation, a multi-stage hierarchy can be applied to perform the analysis more efficiently (Dursun et al., 2011a). Some studies organize these aspects in criteria and sub-criteria levels (Abessi and Saeedi, 2010; Dursun and Karsak, 2010; Dursun et al., 2011a; Hung et al., 2007; Javaheri et al., 2006; Karamouz et al., 2007) and some others omit the upper level and only use a unique level as sub-criteria (Dursun and Karsak, 2010; Dursun et al., 2011b; Karagiannidis et al., 2010; Hatami-Marbini et al., 2013).

Hung et al. (2007) developed a combination of multi-criteria decision making (MCDM) and consensus analysis model (CAM) to support a decision making framework in municipal solid waste management (MSWM)(Hung et al., 2007). Dursun et al. (2011a) proposed two MCDM techniques for conducting an analysis based on multi-level hierarchical structure and fuzzy logic for the evaluation of healthcare waste treatment alternatives (Dursun et al., 2011a). Abessi et al. (2010) used a GIS-based technique of analytical hierarchy process for hazardous waste landfill siting (Abessi and Saeedi, 2010). Hatami et al. (2013) proposed a new fuzzy grouping method for assessment of hazardous waste recycling (HWR) facilities, focusing on safety and health assessment of eight HWR facilities based on six attributes (Hatami-Marbini et al., 2013).

A few available alternatives for HCW treatment were considered by some researchers (Abessi and Saeedi, 2010; Al-Khatib and Sato, 2009; Hatami-Marbini et al., 2013; Javaheri et al., 2006). Additionally, some others categorized the health-related aspects under environmental and technical criteria (Hung et al., 2007; Dursun et al., 2011a). Based on the study of Morrissey and Browne (2004), the environmental, economic and social aspects were not assigned simultaneously in most studies regarding to the solid waste management (Morrissey and Browne, 2004).

In this study, we employed a facile decision-making method according to fuzzy logic for evaluating alternatives for treatment of the health-care wastes of Qom hospitals.

2. Material and methods

In this section, first, some useful definitions are presented to describe the mathematical background of fuzzy logic. In the second sub-section, the hierarchical distance-based fuzzy multi-criteria group decision making (DBF –MCDM) approach has been presented.

2.1. Fuzzy sets theory

Definition 1. A fuzzy set can be determined by Eq. (1):

$$\tilde{A} = \left(X, \mu_{\tilde{A}}(x)\right) \quad (1)$$

where X is the space on which the fuzzy set is defined, and $\mu_{\tilde{A}}(x) \rightarrow [0,1],\ x \in X$ the membership function of the set (Dubois and Prade, 1978).

Definition 2. As illustrated in Fig. 1, a triangular fuzzy number $\tilde{A}$ is identified with a triplet (a_1, a_2, a_3) which its membership function can be represented as follows (Eq.1) (Zimmermann, 2001):

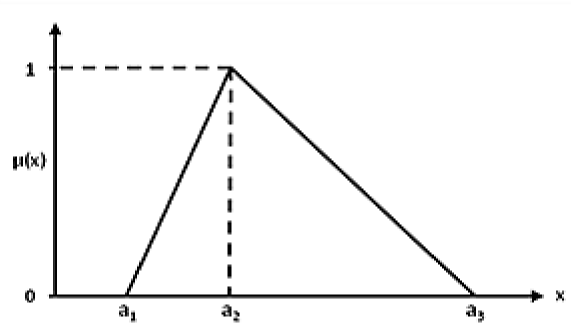

Fig. 1. A triangular fuzzy number Ã

Applying a triangular fuzzy number, due to its simplicity in comparison with trapezoid fuzzy number, is intuitively easy for decision-makers to utilize. Furthermore, because of the subjective, conceptual and vigorous nature of the available information, modeling according to triangular fuzzy numbers is an efficient approach for organizing the decision-making problems (Kahraman, 2008; Zimmermann, 2001).

Definition 3. A linguistic variable can be defined as a variable having values stated in thye linguistic terms. The human judgments are typically imprecise having intrinsic vagueness, so that, it is favored for the experts expressing the judgments through the linguistic terms. The linguistic terms are variables enabled to express the qualitative data. A linguistic variable is usually comprising an ordinary phrase using in normal language illustrating inexact number-free data (Zadeh, 1975).

Definition 4. The criteria $\alpha_1, \alpha_{2...}, \alpha_n$ are the appraisal tools assigning to the alternative. The assumption that criteria are in the relevancy with their consecutive alternatives should be considered. The alternatives are expressed as $A_1, A_{2...}, A_m$. For certain alternative A_i, the relative value of criterion α_j is assigned by a rating and introduced as r_{ij}. Furthermore, the importance of an assumed criterion α_j is apportioned using a coefficient of weighting, identified as w_j. Consequently, the alternative A_i obtains the weighted average rating as follows (Eq. 2):

$$\bar{r}_i = \frac{\sum_{j=1}^{n} w_i r_{ij}}{\sum_{j=1}^{n} w_i} \quad (2)$$

Comparing and ranking the final ratings $\bar{r}_1, \bar{r}_2, ..., \bar{r}_m$ are performed to judge the relevant values of the different alternatives (Baas and Kwakernaak, 1977) .

Definition 5. If $\tilde{n}$ is considered as a triangular fuzzy number and $n_l^{\alpha} \succ 0, n_u^{\alpha} \leq 1, \alpha \in [0,1]$, then $\tilde{n}$ is called a normalized positive triangular fuzzy number (Chen, 2000).

Definition 6. The ideal solution $A^* = (r_1^*, r_2^* \cdots r_n^*)$ and also the anti-ideal solution $A^- = (r_1^-, r_2^- \cdots r_n^-)$ are defined where $r_j^* = (1,1,1)$ and $r_j^- = (0,0,1)$ for $j = 1,2...,n$. (Karsak and Ahiska, 2005).

Definition 7. The distance measure $d_v(\tilde{A}, \tilde{B},)$ is applied to indicate the distance between the fuzzy numbers $\tilde{A} = (\alpha_1, \alpha_2, \alpha_3)$ and $\tilde{B} = (b_1, b_2, b_3)$ as follows (Eq. 3) (Bojadziev and Bojadziev, 1995):

$$d_v(\tilde{A}, \tilde{B}) = \frac{1}{2}\{max(|a_1 - b_1|, |a_3 - b_3|) + |a_2 - b_2|\} \quad (3)$$

The distance formula can be applied to determine the trapezoidal area. The smaller trapezoid base is attributed to the greater values of $|\alpha_1 - b_1|$ or $|\alpha_3 - b_3|$. Also, the greater trapezoid base is expressed using the values of $|\alpha_2 - b_2|$ and the height of trapezoid is 1. (Dursun et al., 2011c; Yekta et al., 2015).

2.2. Hierarchical distance-based fuzzy Multi-criteria group decision making (DBF –MCDM) approach

The fuzzy multi-criteria group decision making approach can address the decision problems including a multi-level hierarchical structure which has been equipped with attributes of qualitative performance (Dursun et al., 2011a). The distance-based fuzzy MCDM approach has been introduced by Karsak (2002) for selecting the technology alternative (Karsak, 2002). The DBF-MCDM is constructed according to the closeness to the ideal alternative concept. Also, DBF-MCDM has the potential of including both crisp and fuzzy data.

Usually, the performance attributes can be organized in multi-level hierarchy when they are in large numbers. The multi-level hierarchy enables the analysis to be done more efficiently. Here, a subversion known as “multi-expert” from the algorithm of hierarchical DBF-MCDM is applied which originally introduced by Karsak and Ahiska (2005) and later represented by Dursun et al (2011a). The following successive steps present the implementation of hierarchical DBF-MCDM approach:

Step 1. Establish a decision-makers team of z experts ($l = 1, 2..., z$). Introduce the alternatives, necessary criteria, and attributed sub-criteria.

Step 2. Assemble the decision matrices that comprise the importance weights of criteria and attributed sub- criteria. The decision matrices should also be included the fuzzy assessments in relation with sub-criteria for each decision-maker.

Step 3. Introduce the mathematical signs used for representation of the criteria, sub-criteria, decision makers and alternatives and their relationships as depicted in Table 1.

Table 1. Mathematical signs used for representing the Equations

Definition	*Description*
$i = (1,2...,m)$	Set of alternatives
$j = (1,2...,n)$	Set of criteria
$k = (1,2...,p)$	Set of sub-criteria
$l = (1,2...,z)$	Set of decision makers
$\tilde{X}_{ijkl} = (X_{ijkl}^1, X_{ijkl}^2, X_{ijkl}^3)$	Alternative i attributed to sub-criterion k of criterion j.
$\tilde{W}_{jkl} = (W_{jkl}^1, W_{jkl}^2, W_{jkl}^3)$	Importance weight of sub-criterion k of criterion j.
$\tilde{W}_{jl} = (W_{jl}^1, W_{jl}^2, W_{jl}^3)$	Importance weight of criterion j for the lth decision-maker

Step 4. Calculate the aggregated fuzzy assessments of alternatives ($\tilde{X}_{ijkl}$), the aggregated importance weight of sub-criteria ($\tilde{W}_{jkl}$) and the aggregated importance weight of criteria ($\tilde{W}_{jl}$) based on follows (Eqs. 4-6):

$$\tilde{W}_j = \sum_{l=1}^{z} v_l \tilde{W}_{jl} \quad (4)$$

$$\tilde{W}_{jk} = \sum_{l=1}^{z} v_l \tilde{W}_{jkl} \quad (5)$$

$$\tilde{X}_{ijk} = \sum_{l=1}^{z} v_l \tilde{X}_{ijkl} \quad (6)$$

where $v_l \in [0,1]$ represents weight assigned to the lth decision-maker.

Also, $\sum_{l=1}^{z} v_l = 1$. Hence, by using above equations, aggregated ratings of alternatives with respect to each sub-criterion ($\tilde{x}_{ijk}$), aggregated importance weights of sub-criteria ($\tilde{W}_{jk}$) and aggregated importance weights of criteria ($\tilde{W}_j$) can be computed as $\left(X^1_{ijk}, X^2_{ijk}, X^3_{ijk}\right)$, $\left(W^1_{jk}, W^2_{jk}, W^3_{jk}\right)$ and $\left(W^1_j, W^2_j, W^3_j\right)$ respectively.

Step 5. To obtain the unit-free and comparable sub-criteria values, the aggregated decision matrix resulted from step 4 should be normalized. Among the various methods used for data normalization (Murofushi and Sugeno, 2000; Kahraman, 2008), a linear scale transformation was selected. Based on this approach, first the sub-criteria are categorized in two groups known as benefit-related (BR) and cost related (CR) ones as identified in Fig 2. Then, the linear scale transformation is used for data normalization as follows (Eq. 7):

$$\tilde{r}_{ijk} = \left(r^1_{ijk}, r^2_{ijk}, r^3_{ijk}\right) = \begin{cases} \left(\dfrac{x^1_{ijk} - x^-_{jk}}{x^*_{jk} - x^-_{jk}}, \dfrac{x^2_{ijk} - x^-_{jk}}{x^*_{jk} - x^-_{jk}}, \dfrac{x^3_{ijk} - x^-_{jk}}{x^*_{jk} - x^-_{jk}}\right), \\ \quad k \in BR_j; i = 1,2...,m; j = 1,2...,n \\ \left(\dfrac{x^*_{jk} - x^3_{ijk}}{x^*_{jk} - x^-_{jk}}, \dfrac{x^*_{jk} - x^2_{ijk}}{x^*_{jk} - x^-_{jk}}, \dfrac{x^*_{jk} - x^1_{ijk}}{x^*_{jk} - x^-_{jk}}\right), \\ \quad k \in CR_j; i = 1,2...,m; j = 1,2...,n \end{cases} \tag{7}$$

where, $\tilde{r}_{ijk}$ is the normalized value of $\tilde{x}_{ijk}$, x^*_{jk} denotes $max_i x^3_{ijk}$ and x^-_{jk} is $\min_i x^1_{ijk}$. BR_j is the set of benefit-related sub-criteria of criterion j for which the greater the performance value the more its preference, and CR_j is the set of cost-related sub-criteria of criterion j for which the greater the performance value the less its preference. Also, *m* identifies the number of alternatives and *n* denotes the number of criteria.

Step 6. The performance ratings of alternatives at the sub-criteria stage to criteria stage should be aggregated to compute the aggregate performance ratings (APRs) as follows (Eq. 8):

$$\tilde{y}_{ij} = \left(y^1_{ij}, y^2_{ij}, y^3_{ij}\right) = \frac{\sum_{k=1}^{p} \tilde{w}_{jk} \otimes \tilde{r}_{ijk}}{\sum_{k=1}^{p} \tilde{w}_{jk}}, \quad i = 1,2...,m; j = 1,2...,n \tag{8}$$

where, $\tilde{y}_{ij}$ is served as the APR of alternative *i* in relation with criterion j. It should be added that $\otimes$ is the multiplication operator in fuzzy logic.

Step 7. The APRs are normalized at criteria stage with linear normalization method again. Based on this approach and from equation (Eq. 9), the best results acquire the value equal to 1 and the worst ones obtain the value equal to 0.

$$\tilde{\tilde{y}}_{ij} = \left(\tilde{\tilde{y}}^1_{ij}, \tilde{\tilde{y}}^2_{ij}, \tilde{\tilde{y}}^3_{ij}\right) = \left(\frac{y^1_{ij} - y^-_j}{y^*_j - y^-_j}, \frac{y^2_{ij} - y^-_j}{y^*_j - y^-_j}, \frac{y^3_{ij} - y^-_j}{y^*_j - y^-_j}\right), \quad i = 1,2...,m; j = 1,2...,n \tag{9}$$

where, $\tilde{\tilde{y}}_{ij}$ is the normalized APR of alternative *i* with respect to criterion j. $y^*_j = \max_i y^3_{ij}$ and $y^-_j = \min_i y^1_{ij}$.

Step 8. The weighted distances (WDs) from ideal solution and anti-ideal solution may be represented as D^*_i and D^-_i respectively. The value of WD for each alternative can be computed as follows (Eqs. 10-11):

$$D^*_i = \sum_{j=1}^{n} \frac{1}{2}\left\{\max\left(\tilde{w}^1_j \left|\tilde{\tilde{y}}^1_{ij} - 1\right|, \tilde{w}^3_j \left|\tilde{\tilde{y}}^3_{ij} - 1\right|\right) + \tilde{w}^2_j \left|\tilde{\tilde{y}}^2_{ij} - 1\right|\right\}, \quad i = 1,2...,m \tag{10}$$

$$D^-_i = \sum_{j=1}^{n} \frac{1}{2}\left\{\max\left(\tilde{w}^1_j \left|\tilde{\tilde{y}}^1_{ij} - 0\right|, \tilde{w}^3_j \left|\tilde{\tilde{y}}^3_{ij} - 0\right|\right) + \tilde{w}^2_j \left|\tilde{\tilde{y}}^2_{ij} - 0\right|\right\}, \quad i = 1,2...,m \tag{11}$$

Step 9. The proximity of the alternatives to the ideal solution is represented with Ω_i^* and can be calculated using Eq. (12):

$$\Omega^*_i = \frac{D^-_i}{D^*_i + D^-_i}, \qquad i = 1,2...,m. \tag{12}$$

By using the Ω_i^* concept, the distances from ideal and anti-ideal solutions are computed.

Step 10. If the results of Ω_i^* are sorted from the largest to the smallest values, the best alternative is one which has obtained the highest Ω_i^* value and therefore is located in the top of the descending ranking of alternatives.

3. Results and discussion

The discussions with experts from Qom University of Medical Sciences (QUMS) and Qom Municipality Recycling Organization (QMRO) revealed that the HCW generated in the nine active hospitals is almost 4500 kg/24h. Also, there is no central plant for treatment of the HCW (Jonidi et al., 2010) . Among them, only two hospitals with the overall capacity of 1500 kg/24h have been equipped with the HCW treatment systems. Briefly, the current HCW management of Qom hospitals is daily collection of the wastes by QMRO and transportation to the sanitary landfill together with other municipal solid wastes. The vehicles used for the HCW transfer and the landfilling process do not meet the requirements of the National Integrated Solid Waste Act (NISWA). It would appear that the method for HCW collection and disposal is prevalence throughout the country (Dehghani et al., 2008). During the recent years, finding an appropriate approach for the HCW treatment is gaining a lot of attention by the official administrators related to the solid waste management.

The following treatment methods were considered as enforceable alternatives for Qom HCW treatment among the various methods proposed in the NISWA executive regulations (MHME, 2004). Among them:

A_1: Incineration

A_2: Steam Sterilization (Autoclave)

A_3: Chemical Disinfection

A_4: Controlled Landfill

According to the NISWA, the treated HCW from the alternatives A_1, A_2 and A_3 should finally be disposed of in a sanitary landfill.

Six evaluation criteria and twenty-one sub-criteria were defined (Fig. 2). The sub-criteria were further classified as Cost-Related and Beneficial-Related groups. The benefit-related sub-criteria are those with a higher performance value and thus the more preference, and the cost-related sub-criteria are considered as sub-criteria for which the higher the performance value the less its preference.

The evaluations were performed by a team of five decision-makers who were identified as DM_1, DM_2, DM_3, DM_4 and DM_5. DM_1 was a professor of environmental health engineering. DM_2 was a technical advisor specialized in solid waste treatment equipment. DM_3 was an HCW management expert of QUMS. DM_4 was a solid waste expert specialized in landfill operation; and DM5 was a socio-economic advisor specialized in solid waste management. Decision-makers used the linguistic term set shown in Table 2 and illustrated as a fuzzy triangular depiction in Fig. 3.

These linguistic terms assigned by the decision-makers to each criterion and sub-criterion for determining their importance are shown in Table 3. Table 4 represents the ratings of each alternative allocated by the decision-makers with respect to the criteria and sub-criteria.

Table 2. Linguistic term set for criteria and sub-criteria

Linguistic Term	***Fuzzy Value***		
Very low (VL)	0	0	0.25
Low (L)	0	0.25	0.5
Moderate (M)	0.25	0.5	0.75
High (H)	0.5	0.75	1
Very High (VH)	0.75	1	1

The importance of criteria and sub-criteria (see Table 3) were aggregated by using Eqs. (4) and (5). The aggregated importance of the criteria and sub-criteria weights is represented in Table 5. The aggregated ratings of alternatives (Table 6) were determined by using Eq. (6) and the data derived from Table 4. It should be noted that the decision-makers were considered with equal weights v_i in this study and consequently $v_1 = v_2 = v_3 = v_4 = v_5 = 0.2$ (Dursun et al., 2011a). The normalized ratings of alternatives with respect to the sub-criteria were computed using Eq. (7), which is based on a linear scale transformation approach.

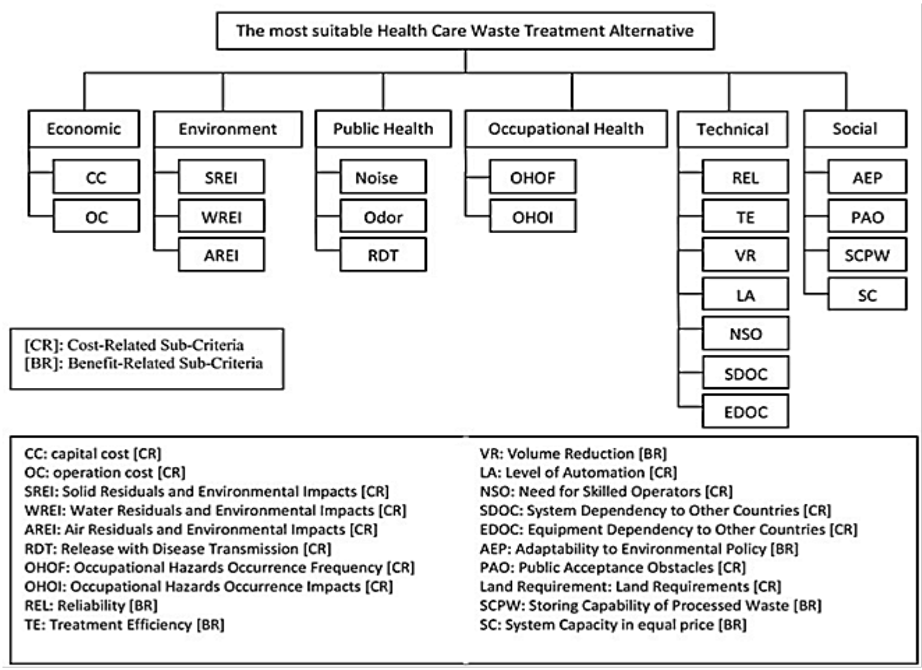

Fig. 2. Hierarchical structure of the problem and identifying the CR and CB nature of criteria and sub-criteria

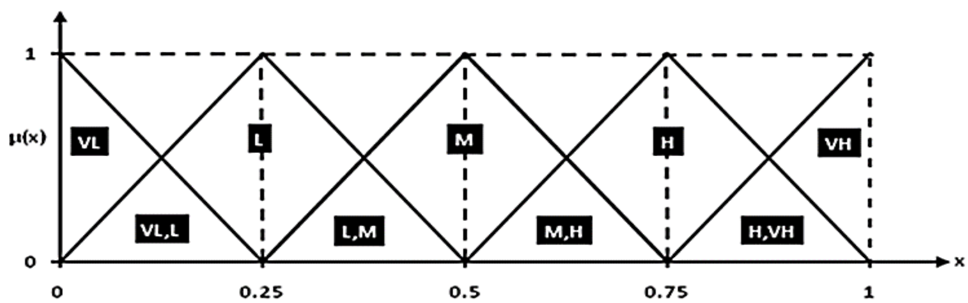

Fig. 3. Linguistic term set in fuzzy depiction

Table 3. Importance of criteria and sub-criteria

Criteria/Sub-Criteria		***DM$_1$***	***DM$_2$***	***DM$_3$***	***DM$_4$***	***DM$_5$***
Economic		M	H	M	VH	H
	CC	H	H	M	H	H
	OC	H	H	VH	H	VH
Environmental		VH	VH	VH	VH	H
	SREI	H	H	VH	H	H
	WREI	VH	H	H	VH	H
	AREI	VH	H	VH	H	H
Public Health		VH	VH	VH	H	VH
	Noise	M	M	L	M	L
	Odor	VH	H	M	H	M
	RDT	VH	VH	VH	VH	VH
Occupational Health		VH	H	H	VH	H
	OHOF	VH	H	H	H	H
	OHOI	VH	H	VH	H	H
Technical		H	M	H	H	VH
	REL	H	VH	H	H	H
	TE	VH	H	VH	H	VH
	VR	H	H	H	L	M
	LA	M	L	H	L	H
	NSO	H	M	H	H	VH
	SDOC	H	M	H	H	M
	EDOC	H	M	H	H	H
Social		VH	H	H	H	M
	AEP	VH	H	H	VH	H
	PAO	M	H	M	L	H
	LR	H	M	M	H	M
	SCPW	H	M	H	H	M
	SC	VH	H	H	H	VH

Table 4. Ratings of alternatives with respect to sub-criteria (I:incineration (A1), S: steam sterilization (A2), C: chemical disinfection (A3), L: control landfill(A4))

Sub-Criteria	**DM$_1$/Alternative**				**DM$_2$/Alternative**				**DM$_3$/Alternative**				**DM$_4$/Alternative**				**DM$_5$/Alternative**			
	I	**S**	**C**	**L**	**I**	**S**	**C**	**L**	**I**	**S**	**C**	**L**	**I**	**S**	**C**	**L**	**I**	**S**	**C**	**L**
CC	VH	H	H	VL	VH	H	H	L	VH	M	H	L	VH	H	H	L	VH	H	H	M
OC	VH	H	H	H	H	H	VH	H	VH	H	H	M	H	H	H	H	VH	H	H	H
SREI	H	L	H	H	M	M	M	H	M	L	H	VH	M	M	H	H	H	L	M	H
WREI	M	M	M	VH	M	L	M	H	H	M	H	H	M	M	M	H	H	L	H	H
AREI	VH	L	M	L	H	M	L	VL	VH	M	L	VL	H	L	M	L	VH	VL	L	L
Noise	L	L	L	L	M	VL	M	VL	L	L	L	L	M	L	L	L	L	L	M	L
Odor	M	H	M	M	H	M	M	H	M	H	M	M	H	M	L	H	M	M	L	H
RDT	M	H	H	VH	M	M	M	VH	L	M	H	VH	M	H	H	H	L	M	M	VH
OHOF	H	H	H	H	VH	M	H	M	H	H	H	H	H	M	VH	H	H	M	H	H
OHOI	VH	H	M	M	H	M	H	H	H	H	H	H	VH	M	H	H	H	M	H	H
REL	M	H	M	H	H	VH	L	H	M	H	M	H	H	H	L	VH	H	VH	H	H
TE	H	VH	M	M	VH	H	H	L	H	VH	M	M	H	H	M	H	H	H	M	M
VR	VH	VL	VL	M	VH	VL	VL	M	VH	VL	VL	H	VH	L	VL	H	VH	L	VL	M
LA	VH	H	H	VL	VH	H	H	VL	H	H	VH	VL	VH	VH	H	VL	H	H	H	L
NSO	VH	H	H	L	H	M	VH	VL	VH	H	H	VL	VH	H	VH	VL	H	M	H	L
SDOC	VH	M	H	L	H	M	VH	L	VH	M	VH	VL	H	M	VH	VL	VH	H	H	VL
EDOC	H	M	VH	VL	VH	M	H	VL	H	H	H	VL	VH	M	VH	VL	VH	M	H	VL
AEP	M	H	M	L	H	H	M	L	M	H	M	VL	H	H	L	L	H	H	M	L
PAO	H	VL	VL	H	VH	L	L	H	H	VL	VL	H	H	L	L	H	H	L	L	VH
LR	H	M	M	L	H	H	H	VL	H	M	M	L	M	M	M	L	H	M	M	L
SCPW	VH	M	M	VH	VH	VL	VL	H	VH	L	M	VH	VH	VL	M	H	H	L	L	H
SC	L	M	L	VH	L	M	VL	VH	L	M	L	H	L	M	VL	VH	VL	L	VL	H

Then, the aggregated performance ratings (APRs) of alternatives with respect to the sub-criteria were calculated by Eq. (8), which was applied to aggregate the sub-criteria values to criteria stage according to the findings of Karsak et al. (2002). The normalized APRs were calculated by using Eq. (9) and results are presented in Table 7 where 0 implies the worst value and 1 represents the best.

The weighted distances from ideal solutions (D_i^*) and anti-ideal solutions (D_i^-) were computed using Eqs. (10) and (11), respectively. Then, the proximity of the alternatives to the ideal solution (Ω_i^*) was calculated by using Eq. (12). The results of the D_i^*, D_i^- and Ω_i^* values are presented in Table 8. After sorting the HCW treatment alternatives according to the magnitude of Ω_i^* values, the following ranking order was achieved (Eq. 13):

$$A_4 \rangle A_2 \rangle A_3 \rangle A_1 \quad (13)$$

As can be inferred from Table 8, controlled landfill (A_4) was the best alternative for treating the HCW generated in Qom hospitals. Dursun et al. (2011a) reported the steam sterilization (i.e., autoclave) as the most suitable alternative for HCW treatment of Istanbul metropolitan in comparison to landfilling, microwaving and incineration. The findings of our study were in disagreement with those of Dursun et al. (2011a).

Hung et al. (2007) studied several alternatives for food wastes including incineration, landfill, composting, hog feeding and anaerobic digestion and found the anaerobic digestion as the most appropriate option. One possible explanation for these discrepancies is the availability of low-cost lands that can be served as landfill areas around the city of Qom. Other important factors resulted in the preference of a controlled landfill were a low annual precipitation (less than 250 mm/year) in central parts of Iran (Javanmard et al., 2010), a low groundwater table (Foltz, 2002), and an appropriate soil texture consisting mainly of clay and loam (NGDI, 2013) that provide a good condition to restrict the migration of HCW leachate. As illustrated in Fig. 4, the areas located in the eastern part of Qom are situated in the vicinity of the great desert of Iran denoted as Kavir, which comprises the alluvial lands with low slop surfaces.

Landfilling is a suitable and low-cost disposal method. However, an improper landfill management and lack of careful separation of solid wastes result in increased human health risks and environmental pollution concerns (Narayana, 2009). (Moritz, 1995). Accordingly, NISWA requires stringent measures such as using an equipped waste transportation system with high levels of safety standard when a “controlled landfill” is chosen as a preferred treatment alternative for the HCW.

Table 5. Aggregated importance weights of criteria and sub-criteria

Criteria/Sub-Criteria		***Aggregated weights***
Economic		(0.550, 0.650, 1)
	CC	(0.550, 0.650, 1)
	OC	(0.600, 0.650, 1)
Environmental		(0.700, 0.800, 1)
	SREI	(0.550, 0.650, 1)
	WREI	(0.650, 0.750, 1)
	AREI	(0.700, 0.750, 1)
Public Health		(0.750, 0.800, 1)
	Noise	(0.150, 0.350, 0.650)
	Odor	(0.550, 0.650, 1)
	RDT	(0.750, 0.800, 1)
Occupational Health		(0.600, 0.700, 1)
	OHOF	(0.500, 0.600, 1)
	OHOI	(0.550, 0.650, 1)
Technical		(0.550, 0.600, 1)
	REL	(0.550, 0.650, 1)
	TE	(0.650, 0.700, 1)
	VR	(0.100, 0.300, 0.600)
	LA	(0.100, 0.250, 0.60)
	NSO	(0.550, 0.600, 1)
	SDOC	(0.500, 0.600, 1)
	EDOC	(0.550,0.650,1)
Social		(0.500, 0.650, 0.950)
	AEP	(0.550, 0.650, 1)
	PAO	(0.400, 0.500, 0.900)
	LR	(0.400, 0.550, 0.900)
	SCPW	(0.300, 0.450, 0.800)
	SC	(0.650, 0.700, 1)

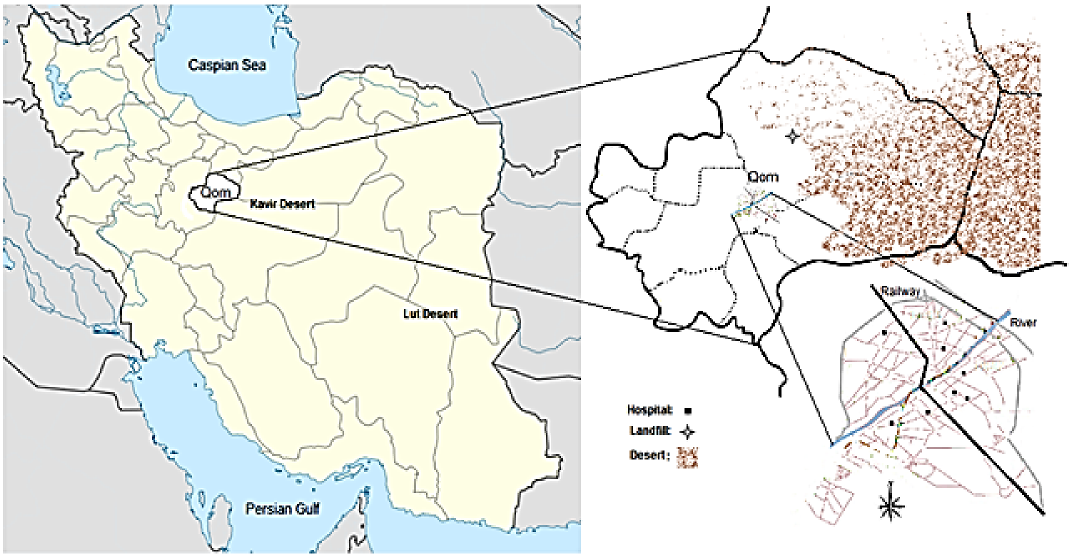

Fig. 4. Hospitals locations and landfill situation of Qom

Table 6. Aggregated ratings of alternatives with respect to sub-criteria

Sub-Criteria	***A_1 (Incineration)***	***A_2 (Steam sterilization)***	***A_3 (Chemical disinfection)***	***A_4 (Controlled landfill)***
CC	(0.750, 1 ,1)	(0.450, 0.700, 0.950)	(0.500, 0.750, 1)	(0.050, 0.250, 0.500)
OC	(0.650, 0.900, 1)	(0.500, 0.750, 1)	(0.550, 0.800, 1)	(0.450, 0.700, 0.950)
SREI	(0.350, 0.600, 0.850)	(0.100, 0.350, 0.600)	(0.400, 0.650, 0.900)	(0.550, 0.800, 1)
WREI	(0.350, 0.600, 0.850)	(0.150, 0.400, 0.650)	(0.350, 0.600, 0.850)	(0.550, 0.800, 1)
AREI	(0.650, 0.900, 1)	(0.100, 0.300, 0.550)	(0.100, 0.350, 0.600)	(0, 0.150, 0.400)
Noise	(0.1, 0.350, 0.600)	(0, 0.200, 0.450)	(0.100, 0.350, 0.600)	(0, 0.200, 0.450)
Odor	(0.350, 0.600, 0.850)	(0.350, 0.600, 0.850)	(0.150, 0.400, 0.650)	(0.400, 0.650, 0.900)
RDT	(0.150, 0.400, 0.650)	(0.350, 0.600, 0.850)	(0.400, 0.650, 0.900)	(0.700, 0.950, 1)
OHOF	(0.550, 0.800, 1)	(0.350, 0.600, 0.850)	(0.550, 0.800, 1)	(0.450, 0.700, 0.950)
OHOI	(0.600, 0.850, 1)	(0.350, 0.600, 0.850)	(0.450, 0.700, 0.950)	(0.450, 0.700, 0.950)
REL	(0.400, 0.650, 0.900)	(0.600, 0.850, 1)	(0.200, 0.450, 0.700)	(0.550, 0.800, 1)
TE	(0.550, 0.800, 1)	(0.600, 0.850, 1)	(0.300, 0.550, 0.800)	(0.250, 0.500, 0.750)
VR	(0.750, 1, 1)	(0, 0.100, 0.350)	(0, 0, 0.250)	(0.350, 0.600, 0.850)
LA	(0.650, 0.900, 1)	(0.550, 0.800, 1)	(0.550, 0.800, 1)	(0, 0.050, 0.300)
NSO	(0.650, 0.900, 1)	(0.400, 0.650, 0.900)	(0.600, 0.850, 1)	(0, 0.100, 0.350)
SDOC	(0.650, 0.900, 1)	(0.300, 0.550, 0.800)	(0.650, 0.900, 1)	(0, 0.100, 0.350)
EDOC	(0.650, 0.900, 1)	(0.300, 0.550, 0.800)	(0.600, 0.850, 1)	(0, 0, 0.250)
AEP	(0.400, 0650, 0.900)	(0.500, 0.750, 1)	(0.200, 0.450, 0.700)	(0, 0.200, 0.450)
PAO	(0.550, 0.800, 1)	(0, 0.150, 0.400)	(0, 0.150, 0.400)	(0.550, 0.800, 1)
LR	(0.450, 0.700, 0.950)	(0.300, 0.550, 0.800)	(0.300, 0.550, 0.800)	(0, 0.200, 0.450)
SCPW	(0.700, 0.950, 1)	(0.050, 0.200, 0.450)	(0.150, 0.350, 0.600)	(0.600, 0.850, 1)
SC	(0, 0.200, 0.450)	(0.200, 0.450, 0.700)	(0, 0.100, 0.350)	(0.650, 0.900, 1)

Table 7. Normalized the aggregated performance ratings

Criteria	***A_1***	***A_2***	***A_3***	***A_4***
Economic	(0, 0.106, 0.524)	(0, 0.369, 0.737)	(0, 0.362, 0.777)	(0.270, 0.654, 1)
Environmental	(0.127, 0.388, 0.713)	(0.086, 0.316, 0.602)	(0.126, 0.386, 0.708)	(0.189, 0.484, 0.806)
Public Health	(0.278, 0.628, 1)	(0.126, 0.483, 0.824)	(0.239, 0.606, 1)	(0.017, 0.269, 0.632)
Occupational Health	(0, 0.312, 0.762)	(0.176, 0.588, 1)	(0, 0.458, 0.959)	(0, 0.402, 0.808)
Technical	(0.183, 0.431, 0.702)	(0.263, 0.505, 0.715)	(0.017, 0.241, 0.546)	(0.473, 0.763, 0.932)
Social	(0.215, 0.504, 0.767)	(0.272, 0.511, 0.759)	(0.207, 0.462, 0.762)	(0.296, 0.569, 0.785)

These measures increase the capitol costs of landfilling as compared to other alternatives. The additional costs associated with the transportation system of untreated HCW mainly include personal protection equipment and use of sealed and double-wall containers equipped with leachate collection tank. Also, the design and construction of the controlled landfills for HCW disposal are costly and must comply with the available regulations (MHME, 2004).These health-related considerations increase the operational costs of the controlled landfills as compared to those of the sanitary landfills, which may be used for final disposal of the treated HCW together with municipal wastes.

The second most suitable alternative was steam sterilization (A_2). This technology has noticeable advantages especially with regard to the environmental and public health aspects (Diaz et al., 2005). Similar to A_1 (incineration) and A_3 (chemical disinfection), the treated HCW from a steam sterilization process should finally be disposed of in a landfill.

The resultant ash of A_1 (incineration) should be sent to a landfill specifically designed for potentially hazardous wastes. Therefore, the advantage of volume reduction during this process may be eclipsed (Alagöz and Kocasoy, 2007). Furthermore, the various occupational health aspects must be considered during operation of an incineration system. The level of automation and the need for well-trained operators are the other drawbacks of incineration.

Large amount of concentrate disinfectants containing mainly hydrogen peroxide are used in chemical disinfection of HCW. These disinfectants increase the health risks to workers and technicians. The efficiency of a disinfectant agent is influenced by a number of parameters such as temperature and pH. These parameters may have an adverse effect on the success of disinfection process (Diaz et al., 2005). It is also reported that chemical disinfection and steam sterilization facilities may produce contaminated under-drains that require further proper treatment (Johannessen et al., 2000).

A significant factor that should be considered in the judgment process of purchasing high-tech equipment is the level of dependency on the foreign suppliers. A better strategy is to encourage the use of the alternative technologies available in the country. Hence, except for the controlled landfill, the other alternatives could not obtain higher levels of linguistic terms by decision-makers for the SDOC and EDOC sub-criteria.

Even though controlled landfill may be a proper disposal option for some types of HCW, wastes such as cytotoxic must be treated properly before disposal. Eventually, landfill is the final disposal method for the residues remaining from the treatment systems(Johannessen et al., 2000). The land requirement sub-criterion (LR) was redefined in this study. The LR concept was separated in two terms: the on-site land requirement (On-SLR) and the off-site land requirement (Off-SLR). The On-SLR means that the land allocated for the HCW treatment was in the hospital area and the Off-SLR indicates the land that assigned for the final disposal of the HCW. Since all the alternatives required a landfill as a final disposal place, then, the LR was not found to be a noticeable disadvantage for the "controlled landfill" option. However, a controlled landfill might need relatively more land in comparison to the sanitary landfill, which was the final disposal of other alternatives. Furthermore, if the controlled landfill was selected, the on-site land requirement (On-SLR) would be much less than that of the other alternatives because no treatment facility must be installed in the hospital area.

Table 8. Ranking of the HCW treatment alternatives

Alternative	D_i^*	D_i^-	Ω_i*	*Rank*
A_4: Controlled Landfill	2.321	3.530	0.603	1
A_2: Seam Sterilization	2.451	3.263	0.571	2
A_3:Chemical Disinfection	2.552	3.254	0.560	3
A_1: Incineration	2.558	3.057	0.544	4

4. Conclusions

Health care waste management comprises the noticeable environmental and public health concerns. These issues are more acute in developing countries due to deficiencies in HCW management, resulting in environmental (water, air and soil) contamination and public health crises particularly in relation with increasing contagious diseases.

Assessment of the available alternatives for HCW treatment is a complicated group decision-making issue that needs to consider the conflicting aspects with the participation of an expert group. The MCDM approaches are not efficient tool because of deterministic or random nature in their classical forms for group decision-making processes. Those approaches contain vague and linguistic data.

An efficient approach was performed by applying the evaluation criteria and their associated sub-criteria on a hierarchical structure. Twenty-one sub-criteria attributed to six criteria were structured in a multi-level hierarchy model. The prepared decision processes allowed the decision-makers to employ linguistic concepts, and thus decreased the cognition problems during the evaluation process.

A hierarchical distance-based fuzzy multi-criteria group decision-making (DBF –MCDM) approach was presented to avoid the problems that happen when the classical decision-making approaches are employed for evaluating the HCW treatment alternatives.

In the present study, a new configuration of criteria and sub-criteria was proposed. Traditionally, four criteria including financial, environmental, technical and social aspects were employed in similar studies. Use of a hierarchy comprising the public health and occupational health aspects as the independent criteria enabled the decision-making process to assign more effective evaluations.

System Dependency to Other Countries (SDOC) and Equipment Dependency to Other Countries (EDOC) sub-criteria were added to the technical aspects for obtaining a state of compatibility with the socioeconomic condition, which restrict the level of dependency on the foreign companies.

The land requirement (LR) was redefined and classified as In-SLR (on-site land requirement) and Of-SLR (off-site land requirement) based on the assumption that all alternatives can be applied as on-site options except for "controlled landfill".

The decision-making approach proposed "controlled landfill", A_4, as the most appropriate HCW treatment alternative for Qom and "steam sterilization", A_2, as the second alternative treatment option. It should be mentioned that the DBF–MCDM approach proposed in this research was simple enough and may easily be reorganized to apply for situations with similar HCW management issues.

Applying the DBF–MCDM enables the decision-making team to better recognize the discrepancies and resemblances of their judgments. In addition, the DBF–MCDM procedure justifies both ideal and anti-ideal solutions simultaneously. This helps decision-makers to have more tangible judgments.

The main limitation involved in this work and the other similar experiments is the high fluctuations of the national currency, which affects some major sub-criteria especially the capital costs (CC) and the operational costs (OC). Therefore, this may change the ranking arrangement of the alternatives during a short-term assessment. Consequently, the ability of stakeholders to certainly confirm the reports of decision makers for a long-term planning may be limited.

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