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A GREY-BASED ASSESSMENT MODEL TO EVALUATE HEALTH-CARE WASTE TREATMENT ALTERNATIVES IN LIBYA

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Abstract. *Medical waste is a problem which haunts environmental officials, considering the many environmental and health risks it causes, as well economic losses. Perhaps the single most important resolve that top management should consider as regards medical waste management is to select an appropriate technology to address it. Such a decision is so complex because there are many criteria that decision-makers should take into consideration. The objective of this paper is to develop a grey based decision-making model for evaluating health-care waste treatment alternatives in Libya. This was based on investigating the reality of medical waste management in Libya by collecting data from the most important and largest public hospitals in the major Libyan cities. These data were compiled through direct contact with these hospitals and from the Libyan Medical Waste Organization website. This paper makes trade-offs between four technologies used in waste treatment, according to five criteria. The results show that microwave is the best technology, followed by steam sterilization, while landfilling comes as the last option.*

Key words: *Healthcare waste, Environment, Grey decision, Management*

1. Introduction

Nowadays health-care waste (HCW) management has become a crucial public health and environmental issue particularly in developing countries. This is mainly due to direct result of industrial development and rapid population growth as well as the number and size of health care facilities (Liu et al., 2015). HCW refers to a special category of waste generated by health care facilities and laboratory facilities operating in hospital settings (Dursun et al., 2011a; Liu et al., 2013). It typically includes infectious pathogens, toxic chemicals, heavy metals, etc., which is potentially hazardous to human health and the public environment (Dursun et al., 2011a; WHO, 2004). According to the World Health Organization (WHO), wastes

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from health-care institutions can be classified into nine main categories as follows (Prüss-Üstün et al., 1999):

– Infectious waste: Waste suspected to contain pathogens e.g. laboratory cultures, waste from isolation wards, tissues (swabs), materials, or equipment that have been in contact with infected patients, excreta;
– Pathological waste: recognizable body parts and contaminated animal carcasses;
– Sharps: Sharp waste e.g. needles, infusion sets, scalpels, knives, blades, broken glass;
– Pharmaceutical waste: Waste containing pharmaceuticals e.g. pharmaceuticals that are expired or no longer needed; items contaminated by or containing pharmaceuticals (bottles, boxes);
– Genotoxic waste: highly hazardous, mutagenic, teratogenic or carcinogenic, such as cytotoxic drugs used in cancer treatment and their metabolites;
– Chemical waste: Waste containing chemical substances e.g. laboratory reagents, film developer, disinfectants that are expired or no longer needed, solvents;
– Wastes with high content of heavy metals: Batteries, broken thermometers, blood-pressure gauges;
– Pressurized containers: Gas cylinders, gas cartridges, aerosol cans;
– Radioactive waste: such as glassware contaminated with radioactive diagnostic material or radio therapeutic materials.

WHO has advocated that hospital waste is considered as special waste and it is now acknowledged that certain categories of medical waste are among the most hazardous and potentially dangerous of all waste arising in communities (WHO, 2004). Improper waste management can cause environmental pollution and numerous harmful diseases to the human being. Therefore, how to select safe and effective treatments and disposal of HCW is significantly important for the public health and human well-being.

In the literature, a number of studies have been conducted in various contexts to assess HCW management practices. These studies used a variety of methods and techniques to manage HCW. On one side, a number of studies have been developed based on adopting the prepared questionnaires, field research and personnel interviews (Hangulu and Akintola, 2017; Patwary et al., 2011; Manga et al., 2011). On the other side, the selection of the best treatment and disposal technology for HCW management can be considered as a complex multi-criteria decision making (MCDM) problem and requires an extensive evaluation process of the potential disposal practices. Many potential evaluation criteria, such as economic, technical, environmental and social criteria and their related sub-criteria, must be considered in the selection procedure of a HCW treatment alternative (Dursun et al., 2011a; Dursun et al., 2011b; Kazimieras Zavadskas et al., 2016; Iglesias et al., 2008). Therefore, classical MCDM techniques, such as analytic hierarchy process (AHP), have been applied to many case studies for assessment of technologies used for hospital waste management (Brent et al., 2007; Karamouz et al., 2007; Hsu et al., 2008; Karagiannidis et al., 2010). Some researches were conducted using grey theory (Thakur and Ramesh, 2015), or a hybrid grey-AHP approach to select the best HCW treatment method (Thakur and Ramesh, 2017).

Due to the complicated relationships among the multiple and hierarchical evaluation criteria, efficient decision models are required to select the most appropriate HCW treatment technology. Hence, many approaches were presented and incorporated to trade-off multiple conflicting criteria with the involvement of a group of decision makers, such as, the VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR), Multi-Objective Optimization by Ratio analysis plus Full Multiplicative Form (MULTIMOORA), Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) (Liu et al., 2013; Liu et al., 2014; Lu et al., 2016). In real life, decision making problems are evaluated by the experts based on the ratings of alternatives and the relative weights of criteria by utilizing the linguistic terms rather than the numerical values. This is because the decision makers' judgments are usually vague and the linguistic terms are more intuitive for them to express the preferences (Liu et al., 2014; Lu et al., 2016). Furthermore, decision makers express their personal assessments based on using multi-granularity linguistic term sets (Liu et al., 2014; Lu et al., 2016; Morente-Molinera et al., 2015). Therefore the potential assessment of HCW disposal cannot be quantified precisely where they are qualitative in nature.

In many developing countries, medical wastes are still handled and disposed of together with other domestic wastes, thus posing significant health risks to municipal workers, the general population and the environment (WHO, 2004; Patwary et al., 2011). According to a survey of the WHO on HCW management in 22 developing countries, the proportion of health care institutions with inappropriate waste disposal methods was between 18% and 64% (WHO, 2004). A study conducted in Sudan identified that the HCW management practices observed in Khartoum state hospitals were not fully safe and have harmful environmental effects, which was characterized by absence of continuous segregation, collection, transportation and final disposal methods of pathological and other medical wastes (Ahmed et al., 2014). In Ethiopia, like other African countries health care wastes in different hospitals are managed improperly. A study conducted in Debre Birhan zonal hospital identified that healthcare wastes were stored, collected, transported and disposed in a manner that creates health problems to the health worker, waste handler and the community (Esubalew, 2007). In Ghana, a study analyzed the healthcare waste management practices in the Greater Accra Region, Ghana. It was concluded that healthcare centers in the Greater Accra Region do not abide to the accepted healthcare waste management policy of Ghana (Asante et al., 2014). In Nigeria, a study conducted to assess the HCW management practices by hospital staff. The study involved the survey of a cross section of four tertiary health institutions. The study showed that there is significant variation in healthcare waste management practices and the sustainability factors. It was found that that the health institutions adopts minimal activities of recycling, reduce and reuse, although not regularly (Uwa, 2014). In Libya, very few studies on hospital waste have been conducted (Altabet, 2004; Alhamroush and Altabet, 2005; Sawalem et al., 2009). These studies are concerned with the classification of waste and present practices such as available procedures, techniques, and methods of handling and disposing of hospital waste. As can be noted that none of the previous studies investigated the evaluation of HCW management methods. Despite Libya having issued a number of laws and rulings regarding environmental issues, but these do not include specific mandates concerning the management of HCW (Sawalem et al., 2009). In fact, there are no clearly defined regulations about the proper management of HCW in Libya. As mentioned earlier, medical wastes in Libya are also treated and disposed together with other domestic wastes. Therefore, an appraisal of the current situation regarding hospital waste management in Libya is essential. The aim of this work is to use a grey based assessment approach to find a compromised priority ranking of treatment alternatives according to the established criteria for a disposal method selection problem in HCW management.

The rest of this paper is organized as follows: The situation of medical waste management in Libya is provided in Section 2. In Section 3, a grey system theory is introduced. The case study for evaluating HCW treatment alternatives for Libya is addressed in Section 4. In Section 5, results are provided along with discussion focusing on comparative analysis. Finally, conclusions and directions for future research are given in Section 6.

2. Medical Waste Management Situation in Libya

There are several methods of healthcare waste treatment such as incineration, steam sterilization, microwaving, landfilling, mechanical/ chemical disinfection, and plasma pyrolysis. Each of them has its own advantages and disadvantages. Healthcare waste incineration has been the major technique used in many countries, for many years, to dispose of medical waste. It is characterized by its relatively low financial cost in comparison with some other known waste treatment techniques. Also, it reduces the remaining waste volumes, which is very important for countries producing enormous amounts of waste and suffering from insufficient space and land for use in sanitary land filling (Ghasemi and Yusuff, 2016). Another important advantage of incinerators is that there is no need for waste segregation that would entail additional costs, as incineration process can almost dispose of certain types of waste arising from hospitals. By contrast, there are several constraints on incinerating and landfilling healthcare wastes as such waste can be a major source of dioxin and furan pollution that may pose health problems (Ghasemi and Yusuff, 2016). Some countries have begun to abandon the use of these technologies because of the health risks that it may cause to employees or to people living nearby, and also for its impact on the environment. In Libya, in the late 1970s and early 1980s, the authorities emphasized the need for, at least, one incinerator as a condition for building new hospitals (MWO, 2019).

In this study, to investigate current practices of medical waste management in some hospitals in Libya, data was collected from 11 public hospitals of 8 cities in different regions of Libya which shown in figure 1. The data was collected through direct contact with those hospitals and from Libyan Medical Waste Organization (MWO). It was found that all hospitals have installed incinerators for medical waste disposal, but are no longer used as a result of aging of incinerators, smoke emission and complaints from residents. Currently, the common types of medical waste disposal methods used by hospitals is collecting medical waste from the hospital in the backyard and is then burnt in open air or disposed in municipal dumps.

This study uses a grey-based approach to select the best techniques for treating health care waste. Decision makers' comparison judgments and extent analysis method is used to decide the final priority of different decision criteria. To the best knowledge of the authors, there is no literature for medical waste treatment technique selection in Libya. An attempt in this regard could enhance decision makers for selecting the best techniques for healthcare waste treatment.

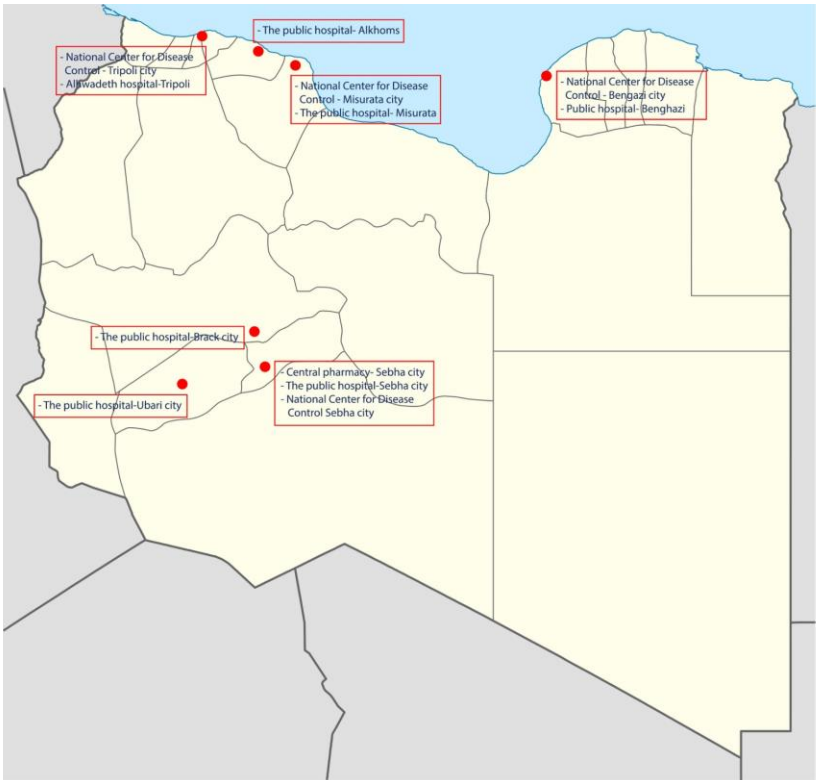

Figure 1: Distribution of hospitals for the case study in Libya

3. Grey Systems Theory

The Multi-Criteria Decision Making (MCDM) problems have received considerable attention from various researchers recently (Roy et al., 2018; Đorđević et al., 2019; Anthony et al., 2019). The Grey systems theory, introduced by Deng in the early 1980s (Deng, 1982), is a methodology that used to solve problems involving incomplete information or small samples (Eshtaiwi et al., 2017). The technique works on uncertain systems with partially known information by generating, mining, and extracting useful information from available data (Badi et al., 2018). Grey theory considers that although the objective system appears complex, with a small amount of data, it always has some internal laws governing the existence of the system and its operation (Liu et al., 2010). It uses a Black-Grey-White colour to describe complex systems. A grey number is a kind of figure that we only know the range of values, and do not know an exact value (Liu et al., 2012; Abdulshahed et al., 2017). This number can be an interval or a general number set to represent the degree of uncertainty of information. Grey systems theory in a decision-making process is very useful, and could be used to tackle the disadvantage of AHP. This section describes the basics about Grey systems theory and Grey numbers in order to understand the model.

3.1 Definition of grey number

Let X is the universal set. Then a Grey set G of X is defined by its two mappings $\overline{\mu}_G(X)$ and $\underline{\mu}_G(X)$: $\overline{\mu}_G(X) : X \longrightarrow [0,1]$ and $\underline{\mu}_G(X) : X \longrightarrow [0,1]$ such that $\overline{\mu}_G(X) \geq \underline{\mu}_G(X)$, $x \in X$. Since the lower limit $\otimes G = [\underline{G}, \infty)$ and upper limit $\otimes G = (-\infty, \overline{G}]$ can possibly be estimated, G is defined as an interval grey number $\otimes G = [\underline{G}, \overline{G}]$ where $\underline{G} > \overline{G}$. Let t be the information, $\overline{G}$ the upper, $\underline{G}$ the lower limit then $\underline{G} \leq t \leq \overline{G}$ if $\underline{G} = \overline{G}$ then $\otimes G$ is a white number with a crisp value which shows the existence of full knowledge. On the contrary, a black number is a grey number one known nothing about it (Liu et al., 2012).

3.2 Basic operations on Grey numbers

The arithmetic of grey numbers is similar to interval value (Liu et al., 2012; Li et al., 2007) and the operation rules of general grey numbers can be defined as operation rules of real numbers (Abdulshahed et al., 2017).

Addition: $\otimes G_1 + \otimes G_2 = [\underline{G}_1 + \underline{G}_2, \overline{G}_1 + \overline{G}_2]$

Subtraction: $\otimes G_1 - \otimes G_2 = [\underline{G}_1 - \overline{G}_2, \overline{G}_1 - \underline{G}_2]$

Multiplication:

$\otimes G_1 \times \otimes G_2 = [min(\underline{G}_1 \underline{G}_2, \underline{G}_1 \overline{G}_2, \overline{G}_1 \underline{G}_2, \overline{G}_1 \overline{G}_2), max(\underline{G}_1 \underline{G}_2, \underline{G}_1 \overline{G}_2, \overline{G}_1 \underline{G}_2, \overline{G}_1 \overline{G}_2)]$

Division: $\otimes G_1 \div \otimes G_2 = [\underline{G}_1, \overline{G}_1] \times \left[\frac{1}{\underline{G}_2}, \frac{1}{\underline{G}_2}\right]$

Length of grey number: $L(\otimes G) = [\overline{G} - \underline{G}]$

Comparison of grey numbers: the possibility degree of two grey numbers is expressed as:

$$P\{\otimes G_1 \leq \otimes G_2\} = \frac{max\left(0, L^* - max(0, \overline{G}_1 - \underline{G}_2)\right)}{L^*}$$

Where $L^* = L(\otimes G_1) + L(\otimes G_2)$

According to this comparison of two grey numbers, there may be four distinct outcomes:

If $\otimes G_1 = \otimes G_2$ then $P\{\otimes G_1 \leq \otimes G_2\} = 0.5$ if $P\{\otimes G_1 > \otimes G_2\}$ then $P\{\otimes G_1 \leq \otimes G_2\} = 1$

If $\otimes G_1 < \otimes G_2$ then $\{\otimes G_1 \leq \otimes G_2\} = 0$

If $P\{\otimes G_1 \leq \otimes G_2\} > 0.5$ then $\otimes G_2 > \otimes G_1$

Otherwise if $P\{\otimes G_1 \leq \otimes G_2\} < 0.5$ then $\otimes G_2 < \otimes G_1$

3.3 The Grey model

Step 1. Determine the attribute weights: Attribute weight W_j can be calculated as follows (Li et al., 2007):

$$\otimes W_j = \frac{1}{K}[\otimes W_j^1 + \otimes W_j^2 + \cdots + \otimes W_j^K] \tag{1}$$

$$\otimes W_j^K = [\underline{W}_j^K, \underline{W}_j^K] \tag{2}$$

Step 2. Alternatives evaluated by the decision makers: decision makers use linguistic or verbal variables when evaluating alternatives according to various attributes.

$\otimes G_{ij}^{K}, (i = 1,2, \dots, m; j = 1,2, \dots, n)$ is the attribute value given by the kth decision maker to any attribute value of the alternative. In grey system this value is shown as, $\otimes G_{ij}^{K} = \left[\underline{G}_{ij}^{K}, \overline{G}_{ij}^{K}\right]$ and computed as:

$$\otimes G_j = \frac{1}{K}\left[\otimes G_j^1 + \otimes G_j^2 + \cdots + \otimes G_j^K\right]$$

Step 3. The construction of Grey Decision Matrix:

$$\boldsymbol{G} = \begin{bmatrix} \otimes \boldsymbol{G}_{11} & \otimes \boldsymbol{G}_{12} & \cdots & \cdots & \otimes \boldsymbol{G}_{1n} \\ \otimes \boldsymbol{G}_{21} & \otimes \boldsymbol{G}_{22} & \cdots & \cdots & \otimes \boldsymbol{G}_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \otimes \boldsymbol{G}_{m1} & \otimes \boldsymbol{G}_{m2} & \cdots & \cdots & \otimes \boldsymbol{G}_{mn} \end{bmatrix} \tag{3}$$

Step 4. The normalization of Decision Matrix:

$$\boldsymbol{D}^{*} = \begin{bmatrix} \otimes \boldsymbol{G}_{11}^{*} & \otimes \boldsymbol{G}_{12}^{*} & \cdots & \cdots & \otimes \boldsymbol{G}_{1n}^{*} \\ \otimes \boldsymbol{G}_{21}^{*} & \otimes \boldsymbol{G}_{22}^{*} & \cdots & \cdots & \otimes \boldsymbol{G}_{2n}^{*} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \otimes \boldsymbol{G}_{m1}^{*} & \otimes \boldsymbol{G}_{m2}^{*} & \cdots & \cdots & \otimes \boldsymbol{G}_{mn}^{*} \end{bmatrix} \tag{4}$$

For a benefit attribute $\otimes G_{ij}^{*}$ is expressed as

$\otimes G_{ij}^{*} = \left[\frac{\underline{G}_{ij}}{G_j^{max}}, \frac{\overline{G}_{ij}}{G_j^{max}}\right]$ where $G_j^{max} = max_{1<i<m}\{\overline{G}_{ij}\}$ and for a cost attribute $\otimes G_{ij}^{*}$ is expressed as

$\otimes G_{ij}^{*} = \left[\frac{G_j^{min}}{\overline{G}_{ij}}, \frac{G_j^{min}}{\underline{G}_{ij}}\right]$ where $G_j^{min} = min_{1<i<m}\{\underline{G}_{ij}\}$.

Step 5. Weighted Normalized Grey Decision Matrix normalized D^{*} matrix is weighted by the $\otimes V_{ij} = \otimes G_{ij}^{*} X \otimes W_j$

Process which establishes the weighted normalized grey decision matrix D_W^{*}.

$$\boldsymbol{D}_{W}^{*} = \begin{bmatrix} \otimes \boldsymbol{V}_{11} & \otimes \boldsymbol{V}_{12} & \cdots & \cdots & \otimes \boldsymbol{V}_{1n} \\ \otimes \boldsymbol{V}_{21} & \otimes \boldsymbol{V}_{22} & \cdots & \cdots & \otimes \boldsymbol{V}_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \\ \otimes \boldsymbol{V}_{m1} & \otimes \boldsymbol{V}_{m2} & \cdots & \cdots & \otimes \boldsymbol{V}_{mn} \end{bmatrix} \tag{5}$$

Step 6: Determine the ideal alternative

From a set m alternatives, $S = \{s_1, s_2, \dots, s_m\}$, the ideal alternative S^{max} is determined by:

$$S^{max} = \left\{\left[\max_{1 \le i \le m} \underline{V}_{i1}, \max_{1 \le i \le m} \overline{V}_{i1}\right], \left[\max_{1 \le i \le m} \underline{V}_{i2}, \max_{1 \le i \le m} \overline{V}_{i2}\right]\right\}, \dots, \left\{\left[\max_{1 \le i \le m} \underline{V}_{in}, \max_{1 \le i \le m} \overline{V}_{in}\right]\right\}$$

Step 7. Calculate the grey possibility degree

The grey possibility degree can be obtained by comparing ideal alternatives S^{max} and possible alternatives $S = \{s_1, s_2, \dots, s_m\}$.

$$P\{S_i \le S^{max}\} = \frac{1}{n}\sum_{j=1}^{n} P\{\otimes V_{ij} \le G_j^{max}\}$$

Step 8. Rank the order of alternatives

Rank order of the alternatives according to the grey possibility degree determined in the 7th step. The smaller the grey possibility degree $P\{S_i \leq S^{max}\}$, the better is the rank order of S_i. Otherwise, the rank order is worse.

4. Case study

The qualitative criteria used for the medical waste treatment technique selection in this research are: Net cost per ton, waste residuals, release with health effects, treatment effectiveness, and public acceptance. Table (1) shows the description of these criteria.

Table 1. Criteria description

Criterion	Description
Waste residuals	Describes the material that remains after the process of waste treatment has taken place.
Release with health effects	Refers to health effects related to the exposure to the treatment technique.
Treatment effectiveness	Relates to how well a treatment works in practice or real life.
Net cost per ton	Defines the net cost per ton.
Public acceptance	Refers to the active or passive approval of a certain technology or policy.

A questionnaire was prepared and distributed to four experts who work in different areas related to the medical waste. The first three criteria are cost criteria, while the last two are benefit. The experts have been invited to participate in the determination of the importance of each criterion. The linguistic variables can be expressed in grey numbers by a scale shown in Table 2. The waste treatment techniques were rated for their performances of attributes on grey scales shown in Table 3.

Table 2. The importance of grey number for the weights of the attribute.

Importance	Abbreviation	Scale of grey number $\otimes W$
Very Low	VL	[0.0, 0.1]
Low	L	[0.1, 0.3]
Medium Low	ML	[0.3, 0.4]
Medium	M	[0.4, 0.5]
Medium High	MH	[0.5, 0.6]
High	H	[0.6, 0.8]
Very High	VH	[0.8, 1.0]

Table 3. Linguistic assessment and the associated grey values.

Performance	Abbreviation	Scale of grey number $\otimes \boldsymbol{W}$
Very Poor	VP	[0.0, 1.0]
Poor	P	[1.0, 3.0]
Medium Poor	MP	[3.0, 4.0]
Fair	F	[4.0, 5.0]
Medium Good	MG	[5.0, 6.0]
Good	G	[6.0, 8.0]
Very Good	VG	[8.0, 10.]

The evaluation of the criteria given by the experts by using linguistic variables was collected, as shown in Table 4. Next, the attributes can be weighted using equation (1).

Table 4. The linguistic assessment of the attributes by experts.

C_i	Expert #1	Expert #2	Expert #3	Expert #4	$\otimes \boldsymbol{W}$		Whitening degree
C_1	H	M	MH	MH	0.50	0.63	0.56
C_2	VH	MH	H	H	0.63	0.80	0.71
C_3	VH	VH	VH	H	0.75	0.95	0.85
C_4	H	H	VH	H	0.65	0.85	0.75
C_5	M	VH	MH	L	0.45	0.60	0.53

Table 5 shows the linguistic assessment of the waste treatment techniques which have done by the experts. Transform the linguistic variables into grey numbers according to scales of grey numbers, equation (3). By the assessment of the consequences, grey decision matrix D is calculated.

$$\boldsymbol{D} = \begin{bmatrix} [5.25 \quad 6.75] & [3.75 \quad 5.00] & [0.50 \quad 2.00] & [6.00 \quad 7.75] & [1.75 \quad 3.25] \\ [2.75 \quad 4.00] & [5.00 \quad 6.75] & [6.25 \quad 8.00] & [7.00 \quad 9.00] & [7.00 \quad 9.00] \\ [1.75 \quad 3.50] & [4.75 \quad 6.75] & [5.25 \quad 6.25] & [5.75 \quad 7.75] & [6.25 \quad 8.25] \\ [6.00 \quad 7.50] & [3.00 \quad 4.75] & [2.00 \quad 3.00] & [2.75 \quad 4.25] & [4.00 \quad 5.50] \end{bmatrix}$$

The normalization of Decision Matrix "D" to make the grey elements lying between 0 and 1 as follows:

Table 5. Experts views on waste treatment techniques selection criterion.

C_j	Technique	Expert #1	Expert #2	Expert #3	Expert#4	$\otimes G_{ij}$
C_1	Incineration	G	G	F	MG	[5.25 6.75]
	Steam sterilization	P	MP	F	MP	[2.75 4.00]
	Microwave	P	F	P	P	[1.75 3.50]
	Landfill	VG	MP	VG	MG	[6.00 7.50]
C_2	Incineration	F	VG	MP	VP	[3.75 5.00]
	Steam sterilization	VG	G	G	VP	[5.00 6.75]
	Microwave	G	G	G	P	[4.75 6.75]
	Landfill	F	P	P	G	[3.00 4.75]
C_3	Incineration	P	VP	P	VP	[0.50 2.00]
	Steam sterilization	G	VG	G	MG	[6.25 8.00]
	Microwave	G	VG	G	P	[5.25 7.25]
	Landfill	F	VP	VP	F	[2.00 3.00]

C_4	Incineration	G	VG	G	F	[6.00 7.75]
	Steam sterilization	G	G	VG	VG	[7.00 9.00]
	Microwave	G	VG	VG	P	[5.75 7.75]
	Landfill	G	VP	P	F	[2.75 4.25]
C_5	Incineration	P	VP	VP	G	[1.75 3.25]
	Steam sterilization	VG	VG	G	G	[7.00 9.00]
	Microwave	VG	VG	VG	P	[6.25 8.25]
	Landfill	F	VP	G	G	[4.00 5.50]

The next step is to calculate the weights of the criterion using equation (5); by grey multiplication of weights assigned to criterion with the corresponding elements of normalized grey decision matrix.

$$D_W^* = \begin{bmatrix} [0.13 \quad 0.21] & [0.38 \quad 0.64] & [0.19 \quad 0.95] & [0.50 \quad 0.82] & [0.13 \quad 0.31] \\ [0.22 \quad 0.40] & [0.28 \quad 0.48] & [0.05 \quad 0.08] & [0.58 \quad 0.95] & [0.51 \quad 0.85] \\ [0.25 \quad 0.63] & [0.28 \quad 0.51] & [0.05 \quad 0.09] & [0.48 \quad 0.82] & [0.45 \quad 0.78] \\ [0.12 \quad 0.18] & [0.39 \quad 0.80] & [0.13 \quad 0.24] & [0.23 \quad 0.45] & [0.29 \quad 0.52] \end{bmatrix}$$

The grey possibility degree of the waste treatment techniques for every criterion is determined with reference to the ideal technique S^{max}. The S^{max} is obtained as shown below:

$$S^{max} = \{[0.25 \quad 0.63], [[0.39 \quad 0.80]], [0.19 \quad 0.95], [0.58 \quad 0.95], [0.51 \quad 0.85]\},$$

Every technique is compared with the S^{max} to determine the final crisp value (grey possibility degree). The different values of grey possibility degree of the four different techniques were denoted by incineration, landfilling, microwave, and steam respectively. The result of the comparison is as follows:

$P\{T1 \leq S^{max}\}$= 0.758 $P\{T2 \leq S^{max}\}$=0.719 $P\{T3 \leq S^{max}\}$=0.717 $P\{T4 \leq S^{max}\}$=0.884

The final step is to sort the techniques according to their grey possibility degree in descending order: Closer to the centre point (i.e., zero), better the rank order. According to the probability degree obtained in last step, the rank order will be as follows:

Microwave > Steamsterilization > Incineration > Landfilling

5. Discussion

The evaluation of four HCW treatment alternatives for Libya using a grey based decision making approach yields to microwave as the best treatment method. The microwave is the preferred alternative treatment method for the case study since it minimizes the impact on the environment and demonstrates a commitment to public health. It has also relatively low investment and operating cost when compared with other treatment alternatives.

It can be said that medical waste management in the Libyan hospitals and health centers is in a very bad situation. Even though they often have incinerators to incinerate these wastes, this does not seem to be effective in fact. Most of these incinerators have, in reality, been abandoned or used for short periods of time and then neglected. People dealing with these incinerators are usually janitors who are mostly not qualified in this field. Moreover, maintenance work is almost non-existent, often with insufficient maintenance plans and shortages of spare parts.

It should also be noted that appropriate types of incinerators are not selected on the basis of their size and absorption of the waste quantities expected to be generated at hospitals, or the temperatures they can reach. Choosing small and inadequate incinerators for waste quantities generated has resulted in the exhaustion of these incinerators, due to their overuse, combined with a lack of maintenance. With the increase in complaints from residents living near hospitals about these incinerators plus the causes mentioned above, hospital officials are led to resort to the easiest solutions, which would be to transport medical waste along with municipal solid waste and dump them at open dumping, with consequent significant environmental risks. In fact, studies state that municipal solid waste dumps are often beyond control and waste is treated by burning, burying, or even left in open air without taking any action (Badi et al., 2019). Inappropriate ways of handling solid wastes have resulted in many environmental and health problems, in terms of proliferation of diseases by viruses and micro-organisms, as well as contamination of ground water by untreated medical waste in landfills. Therefore, the problems associated with treatment of HCW should be solved in a manner that minimizes the risks to the public health and human well-being, and the damage to the environment. The results obtained in this paper are consistent with those produced by Dursun et al (Dursun et al., 2011b). As is pointed out in (Dursun et al., 2011b), non-incineration alternative technologies, such as steam sterilization and microwave, are placed in the first and second rankings in view of the fact that they appear to emit fewer pollutants and generate non-hazardous residues. Furthermore, Abd El-Salam indicated that incineration is not an accepted treatment method for solid medical waste due to the risks associated with (El-Salam, 2010).

This paper highlights a standard model that decision makers in the country may benefit from, as it can help them make appropriate resolutions about these issues by choosing, from a range of methods, the most appropriate treatment technology. This conclusion has been reached on the basis of opinions provided by a group of experts in the field of environment and management of medical waste. Finally, this standard model can be generalized especially for those countries with similar circumstances to ours. The outcome of the work has been analysed to provide the decision makers with valuable tool to select the best technique. According to the results in equation **Error! Reference source not found.**, microwave is the most preferred technique, because it has the lowest weight, while steam sterilization is the next recommended technique. The difference between weights of microwave and steam sterilization is small, so it is possible to use either one of them.

6. Conclusion

Health-care waste management problem has been increasing fast caused by the development of urbanization, particularly in developing countries. The aim of this paper is, for the first time, a methodology using a grey based decision making approach is used for evaluating HCW treatment alternatives in Libya. This is an important and urgent decision needs to be taken, while the only way for treatment methods now is to dump and burn the wastes in open spaces. In this regard, a systematic decision making technique with an emphasis on opinion of experts who work in health care and environment sectors was conducted. The results of this study show that microwave is the most suitable technology for HCW treatment, followed by steam sterilization, while landfilling comes at the end of the options. The results of this work can help decision makers to improve the medical care waste management services.

For future research, extensions of the proposed methodology can be developed by integrating both subjective and objective importance weight assessments of the criteria and related sub-criteria. Moreover, for potential practical applications, the proposed method can be easily extended to deal with other management decision making problems, such as environment assessment, human resource management, and supply chain management to further validate the effectiveness and applicability of the proposed method.

References

Abdulshahed, A. M., Badi, I. A. & Blaow, M. M. (2017). A grey-based decision-making approach to the supplier selection problem in a steelmaking company: a case study in Libya. *Grey Systems: Theory and Application,* 7**,** 385-396.

Ahmed, N., Gasmelseed, G. & Musa, A. (2014). Assessment of medical solid waste management in Khartoum State Hospitals. *Journal of Applied and Industrial Sciences,* 2**,** 201-205.

Alhamroush, A. & Altabet, A. (2005). Hospital waste in Misurata (problems, effects and methods of disposal). *Master's thesis. Libya: Medical Technical College, Alfath University*.

Altabet, A. (2004). Medical and chemical waste in dental clinics. Proceedings of the Third Arabic Conference of Environmental Administration: New Trends in Management of Environment Contamination Waste, Arab Administrative Development Organization.

Anthony, P., Behnoee, B., Hassanpour, M. & Pamucar, D. (2019). Financial performance evaluation of seven Indian chemical companies. *Decision Making: Applications in Management and Engineering*.

Asante, B., Yanful, E. & Yaokumah, B. (2014). Healthcare Waste Management; Its Impact: A Case Study Of The Greater Accra Region, Ghana. *International Journal Of Scientific & Technology Research,* 3.

Badi, I., Abdulshahed, A., Shetwan, A. & Eltayeb, W. (2019). Evaluation of solid waste treatment methods in Libya by using the analytic hierarchy process. *Decision Making: Applications in Management and Engineering*.

Badi, I. A., Abdulshahed, A. M., Shetwan, A. & Ballem, M. A. (2018). A grey-based assessment approach to the site selection of a desalination plant in Libya. *Grey Systems: Theory and Application,* 8**,** 366-379.

Brent, A. C., Rogers, D. E., Ramabitsa-Siimane, T. S. & Rohwer, M. B. (2007). Application of the analytical hierarchy process to establish health care waste management systems that minimise infection risks in developing countries. *European Journal of Operational Research,* 181, 403-424.

Deng, J.-L. (1982). Control problems of grey systems. *Systems & Control Letters,* 1, 288-294.

Đorđević, D., Stojić, G., Stević, Ž., Pamučar, D., Vulević, A. & Mišić, V. (2019). A New Model for Defining the Criteria of Service Quality in Rail Transport: The Full Consistency Method Based on a Rough Power Heronian Aggregator. *Symmetry,* 11, 992.

Dursun, M., Karsak, E. E. & Karadayi, M. A. (2011a). Assessment of health-care waste treatment alternatives using fuzzy multi-criteria decision making approaches. *Resources, Conservation and Recycling,* 57, 98-107.

Dursun, M., Karsak, E. E. & Karadayi, M. A. (2011b). A fuzzy multi-criteria group decision making framework for evaluating health-care waste disposal alternatives. *Expert Systems with Applications,* 38, 11453-11462.

El-Salam, M. M. A. (2010). Hospital waste management in El-Beheira Governorate, Egypt. *Journal of environmental management,* 91, 618-629.

Eshtaiwi, M. I., Badi, I. A., Abdulshahed, A. M. & Erkan, T. E. (2017). Assessment of airport performance using the Grey theory method: A case study in Libya. *Grey Systems: Theory and Application,* 7, 426-436.

Esubalew, T. (2007). *Assessment of health care waste generation rate and evaluation of health care waste management in Debre Birhan zonal hospital.* M. Sc. Thesis, School of public health, Addis Ababa University, 12.

Ghasemi, M. K. & Yusuff, R. B. (2016). Advantages and Disadvantages of Healthcare Waste Treatment and Disposal Alternatives: Malaysian Scenario. *Polish Journal of Environmental Studies,* 25.

Hangulu, L. & Akintola, O. (2017). Perspectives of policy-makers and stakeholders about health care waste management in community-based care in South Africa: a qualitative study. *BMC health services research,* 17, 290.

Hsu, P.-F., Wu, C.-R. & Li, Y.-T. (2008). Selection of infectious medical waste disposal firms by using the analytic hierarchy process and sensitivity analysis. *Waste Management,* 28, 1386-1394.

Iglesias, A., Del Castillo, M., Santos, M., Serrano, J. & Oliva, I. (2008). A comparison between possibility and probability in multiple criteria decision making. *Computational Intelligence in Decision and Control.* World Scientific.

Karagiannidis, A., Papageorgiou, A., Perkoulidis, G., Sanida, G. & Samaras, P. (2010). A multi-criteria assessment of scenarios on thermal processing of infectious hospital wastes: A case study for Central Macedonia. *Waste management,* 30, 251-262.

Karamouz, M., Zahraie, B., Kerachian, R., Jaafarzadeh, N. & Mahjouri, N. (2007). Developing a master plan for hospital solid waste management: A case study. *Waste Management,* 27, 626-638.

Li, G.-D., Yamaguchi, D. & Nagai, M. (2007). A grey-based decision-making approach to the supplier selection problem. *Mathematical and Computer Modelling,* 46, 573-581.

Liu, H.-C., Wu, J. & Li, P. (2013). Assessment of health-care waste disposal methods using a VIKOR-based fuzzy multi-criteria decision making method. *Waste management,* 33, 2744-2751.

Liu, H.-C., You, J.-X., Lu, C. & Chen, Y.-Z. (2015). Evaluating health-care waste treatment technologies using a hybrid multi-criteria decision making model. *Renewable and Sustainable Energy Reviews,* 41, 932-942.

Liu, H.-C., You, J.-X., Lu, C. & Shan, M.-M. (2014). Application of interval 2-tuple linguistic MULTIMOORA method for health-care waste treatment technology evaluation and selection. *Waste Management,* 34, 2355-2364.

Liu, S., Fang, Z., Yang, Y. & Forrest, J. (2012). General grey numbers and their operations. *Grey Systems: Theory and Application,* 2, 341-349.

Liu, S., Forrest, J. Y. L. & Lin, Y. (2010). *Grey systems: theory and applications*, Springer.

Lu, C., You, J.-X., Liu, H.-C. & Li, P. (2016). Health-care waste treatment technology selection using the interval 2-tuple induced TOPSIS method. *International journal of environmental research and public health,* 13, 562.

Manga, V. E., Forton, O. T., Mofor, L. A. & Woodard, R. (2011). Health care waste management in Cameroon: A case study from the Southwestern Region. *Resources, Conservation and Recycling,* 57, 108-116.

Morente-Molinera, J. A., Pérez, I. J., Ureña, M. R. & Herrera-viedma, E. (2015). On multi-granular fuzzy linguistic modeling in group decision making problems: a systematic review and future trends. *Knowledge-Based Systems,* 74, 49-60.

MWO. (2019). *Medical Waste Organization MWO* [Online]. Available: https://medicalwaste.org.ly [Accessed 12 November 2019 2019].

Patwary, M. A., O'Hare, W. T. & Sarker, M. H. (2011). Assessment of occupational and environmental safety associated with medical waste disposal in developing countries: a qualitative approach. *Safety science,* 49, 1200-1207.

Prüss-Üstün, A., Giroult, E., Rushbrook, P. & Organization, W. H. (1999). *Safe management of wastes from health-care activities*, World Health Organization.

Roy, J., Adhikary, K., Kar, S. & Pamucar, D. (2018). A rough strength relational DEMATEL model for analysing the key success factors of hospital service quality. *Decision Making: Applications in Management and Engineering,* 1, 121-142.

Sawalem, M., Selic, E. & Herbell, J.-D. (2009). Hospital waste management in Libya: A case study. *Waste management,* 29, 1370-1375.

Thakur, V. & Ramesh, A. (2015). Selection of waste disposal firms using grey theory based multi-criteria decision making technique. *Procedia-Social and Behavioral Sciences,* 189, 81-90.

Thakur, V. & Ramesh, A. (2017). Healthcare waste disposal strategy selection using grey-AHP approach. *Benchmarking: An International Journal,* 24, 735-749.

Uwa, C. U. (2014). Assessment of healthcare waste management practices in Enugu Metropolis, Nigeria. *International journal of environmental science and development,* 5, 370.

WHO, W. H. O. (2004). Safe management of wastes from health-care activities: a summary. World Health Organization.

Zavadskas, K. E., Antucheviciene, J., Adeli, H. & Turskis, Z. (2016). Hybrid multiple criteria decision making methods: A review of applications in engineering. *Scientia Iranica,* 23**,** 1-20.