A new integrated fuzzy MCDM approach and its application to wastewater management

Mehtap Dursun*[1]

Abstract: This paper proposes a fuzzy multi-criteria group decision making methodology that combines 2-tuple fuzzy linguistic representation model, linguistic hierarchies, Decision Making Trial and Evaluation Laboratory (DEMATEL) method and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). The multi-granular linguistic information obtained from decision-makers are unified and aggregated employing linguistic hierarchies and 2-tuple fuzzy linguistic representation model. The weights of the criteria are calculated employing DEMATEL method, which enables to consider inner dependencies among criteria. Then, fuzzy TOPSIS method is utilized to rank the alternatives. The developed methodology is able to handle information in a decision making problem with multiple information sources. Furthermore, it enables managers to deal with heterogeneous information without loss of information. The developed methodology is used to determine the most suitable wastewater treatment (WWT) alternative for Istanbul, the largest city of Turkey that is also listed among the world's most crowded cities.

Keywords: Decision support systems, DEMATEL, Fuzzy sets, Linguistic hierarchies, TOPSIS, 2-tuple fuzzy linguistic representation, wastewater management

1. Introduction

Today, many countries suffer from persistent environmental problems and expect to encounter new problems in the future. Wastewater management is considered as one of the most important environmental problem faced by the developing countries. Protection of public health, surface water quality, and ground water quality requires adequate wastewater treatment [1]. Green environmental practices are increasingly important in combating serious environmental issues.

Wastewater management is based on the conventional approach of collecting the wastewater and transferring it to a treatment works. In view of high cost of conventional wastewater treatment (WWT) systems there is an increasing need to develop low cost methods of treating wastewater particularly that of municipal and industrial origin [2]. The main objective of WWT is generally to allow human and industrial effluents to be disposed of without danger to human health or natural environment. Selection of appropriate WWT technologies that enable sustainable development presents a challenge to national, regional and local policy makers [3]. Recent developments provide many WWT technology options. The most widely used WWT technology is the conventional activated sludge process (ASP). Other technologies have also been developed that use various treatment processes (aerobic or anaerobic, highly mechanized or not highly mechanized, etc) such as trickling filters and biotowers, upflow anaerobic sludge blanket reactors, rotating biological contactors (RBC), aerated lagoons, sequential batch reactor (SBR) [4]. Apart from these, natural WWT systems including stabilization ponds, duckweed ponds, constructed wetlands, are also employed [5].

According to the results of Municipal Wastewater Statistic

Survey conducted in Turkey in 2010, out of 3.58 billion m^3 of wastewater collected by sewerage systems, 48.6% was discharged into rivers, 41.8% into seas, 3.6% into dams, 2.1% into lakes and artificial lakes, 1% on to land, and 2.8% to other receiving bodies. There were 326 municipal WWT plants serving 438 municipalities in 2010. 39 of wastewater treatment plants were physical, 199 were biological, 53 were advanced and 35 were natural. Out of 3.58 billion m^3 of wastewater discharged via sewerage, 2.72 billion m^3 was treated in WWT plants. The rate of advanced treatment was 37.9%, while the rate of biological treatment was 34.3%, the rate of physical treatment was 27.6%, and the rate of natural treatment was 0.2% [6].

In order to promote and support water supply and sanitation programs in the developing countries, great efforts have been made at both international and local levels. Nevertheless, statistical data show that two third of all wastewater are not treated. Furthermore, many WWT plants are not in operations or poorly operated due to the inappropriate treatment technologies and levels.

Appropriate wastewater treatment technologies have been considered as part of sustainable development strategies. Untreated wastewater has serious effects on human health and natural environment. For this reason, selection of the appropriate wastewater treatment alternative is vital for sustainable development. The most suitable alternative is, not only a system providing the best performance at least cost, but it should also be sustainable in terms of meeting the environmental, technical, and social requirements.

For those reasons, this paper focuses on the detailed evaluation of WWT alternatives to determine the most suitable one for Istanbul, although it is worth noting that the decision models developed here are not limited to this specific problem and could very well be applied to wastewater management, in general. The study thus aims to answer the following research questions.

[1] Industrial Engg.,Galatasaray University, İstanbul – 34349, TURKEY
* Corresponding Author: Email: mdursun@gsu.edu.tr

1. What are the evaluation criteria for the selection of appropriate WWT technology?
2. Is there any interaction between the evaluation criteria? How can the weights of the criteria be calculated considering the interactions?
3. How can the imprecise and vague information on wastewater management be incorporated into the analysis?
4. With criteria and weights found in question 1 and 2, how can the most appropriate wastewater treatment alternative be selected utilizing such criteria? In other words, what would be the most appropriate procedure for selection?
5. How could the problem of loss of information of fuzzy linguistic approaches be rectified?
6. How can the managers deal with multi-granular information provided by decision-makers?
7. Which wastewater treatment method is more suitable when considering the environmental, technical, and social requirements?

WWT alternative selection problem involves the consideration of conflicting criteria incorporating vagueness and imprecision with the involvement of a group of experts. The objective of this study is to propose a fuzzy multi-criteria group decision making approach integrating 2-tuple fuzzy linguistic representation model, linguistic hierarchies, decision making trial and evaluation laboratory (DEMATEL) method and fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method for identifying the most suitable WWT alternative.

In fuzzy group decision making approaches, it is expected that decision-makers provide their preferences using a set of previously determined linguistic variables. Because decision-makers have different cultural background and level of knowledge about the problem, they prefer to use non-homogeneous verbal terms with different degrees of uncertainty. In order to process the non-homogeneous data obtained from decision-makers, these data must first be reduced to the same degree of uncertainty. The main problem encountered in this process is data loss. The developed approach uses 2-tuple linguistic representation model and linguistic hierarchies to solve this problem. This approach, developed by Herrera and Martinez [7], deals with the loss of data arises in data processing by expressing the data with 2-tuples that is compose of a "linguistic term" and "closeness to the linguistic term". Thus, the data are shown not only at a specified scale, but also in closeness to the linguistic variables in this measure, and the data set is expanded.

This study employs DEMATEL method to calculate the weights of the criteria. DEMATEL method does not require the unrealistic assumption of the mutual independence of criteria and it provides the calculation of the criteria weights by considering structural casual relationships of complex problems. In case of not using DEMATEL method, the weights of the criteria are determined either using subjective evaluations of decision-makers or weights will be considered equal. In this case, the interactions between the criteria will be ignored and therefore the problem will be unrealistic. Furthermore, when making a decision, humans strive to be both as close as possible to the ideal and as distant as possible from the anti-ideal [8], thus TOPSIS, which is based on the intuitive principle that the preferred alternative should have the shortest distance from the ideal solution and the farthest distance from the anti-ideal solution [9] is used to rank the WWT alternatives. The results of this research are expected to bring about a new line of thought, contributing to the development of decision making and supporting systems in the field of wastewater management.

The contributions of this research can be summarized as follows. First, the developed method is a group decision making process, which enables the group to identify and better appreciate the differences and similarities of their judgments. Second, the proposed approach is apt to incorporate imprecise data into the analysis using fuzzy set theory. Third, the proposed methodology does not require the assumption of the mutual independence of criteria. Fourth, as humans strive to be both as close as possible to the ideal and as distant as possible from the anti-ideal [8], both ideal and anti-ideal solutions are considered simultaneously in the presented approach. Fifth, the linguistic hierarchies and 2-tuple linguistic representation model that rectifies the problem of loss of information faced with other fuzzy linguistic approaches is employed in the developed approach. Finally, the proposed framework enables managers to deal with multi-granular information, and thus, allows for the use of different semantic types by decision-makers.

The rest of the paper is organized as follows. In Section 2, recent literature on the application of multi-criteria decision making (MCDM) methods is given. Section 3 briefly introduces DEMATEL method. Section 4 and Section 5 delineate the 2-tuple fuzzy linguistic representation model and linguistic hierarchies, respectively. Section 6 presents the stepwise representation of the proposed decision making approach. Structure of the wastewater treatment alternative evaluation problem and experts survey are given in Section 7. Section 8 presents results and discussions. Finally, concluding remarks are given in the last section.

2. Literature Review

Multi-criteria decision analysis (MCDA) is both an approach and a set of techniques, with the goal of providing an overall ordering of options, from the most preferred to the least preferred option [10]. MCDA is divided in two groups as multi-objective decision making (MODM) and multi-attribute decision making (MADM). The intention of MCDA methods is to improve the quality of decisions by making choices more explicit, reasonable and effective.

MCDM has grown as a part of operations research, concerned with designing computational and mathematical tools for supporting the subjective evaluation of performance criteria by decision-makers [11]. Recently, several studies have employed MCDM tools and applications to solve area problems such as energy, environment and sustainability, supply chain management, quality management, construction and project management, manufacturing systems, technology and information management.

Literature review indicates that recently developed MCDM methods such as complex proportional assessment (COPRAS), weighted aggregated sum product assessment (WASPAS), the evaluation based on distance from average solution (EDAS), multi-attributive border approximation area comparison (MABAC), multi-attributive ideal-real comparative analysis (MAIRCA), and best worst method (BWM) methods and their modifications have been applied to solve different kinds of problems. Gigovic et al. [12] combined GIS, DEMATEL analytic network process (DANP), and MABAC for selecting the location of wind farms. Gupta and Barua [13] employed BWM and fuzzy TOPSIS for supplier selection. Nie et al. [14] used WASPAS technique for solving solar-wind power station location problem. Mousavi-Nasab et al. [15] integrated COPRAS, TOPSIS, and

data envelopment analysis (DEA) for material selection problem. Peng and Dai [16] proposed MABAC, WASPAS, and COPRAS to solve hesitant fuzzy soft decision making problems. Rathi and Balamohan [17] extended COPRAS under fuzzy environment to deal with fuzzy multi-criteria group decision making problems. Salimi [18] used BWM for quality assessment. Stanujkic et al. [19] extended the EDAS method for the use of grey numbers. Urosevic et al. [20] employed (step-wise weight assessment ratio analysis) SWARA and WASPAS methods for personnel selection in tourism industry. Gigovic et al. [21] combined (geographic information system) GIS and MAIRCA for the selection of depot sites. Keshavarz et al. [22] used EDAS method for supplier selection. Liou et al. [23] combined DANP with COPRAS with grey for green supplier selection. Turanoğlu Bekar et al. [24] employed fuzzy COPRAS for performance measurement in total productive maintenance. Xue et al. [25] introduced interval-valued intuitionistic fuzzy MABAC approach for material selection. Yang et al. [26] evaluated overseas talents in China using BWM. Zavadskas et el. [27] used WASPAS for choosing an optimal indoor environment. Nguyen et al. [28] integrated analytic hierarchy process (AHP) and fuzzy COPRAS for machine tool evaluation. Makhesana [29] utilized COPRAS for rapid prototyping system selection. Pamucar and Cirovic [30] utilized MABAC for the selection of transport and handling resources in logistics centers. Turskis et al. [31] integrated fuzzy AHP and fuzzy WASPAS for construction site selection.

DEMATEL and TOPSIS are also widely used in decision making. Chauan et al. [32] combined entropy and TOPSIS for energy performance evaluation. Onu et al. [33] employed fuzzy TOPSIS for ranking sustainable water supply alternatives. Pamucar et al. [34] introduced hybrid DEMATEL-ANP-MAIRCA model for decision making. Dimic et al. [35] used DEMATEL based ANP model for strategic transport management models. Zyoud et al. [36] integrated fuzzy AHP and fuzzy TOPSIS for water loss management. Alemi et al. [37] used TOPSIS and VIKOR models for oil production rate improvement. Gigovic et al. [38] proposed a model based on GIS and fuzzy DEMATEL method in order for ecotourism development site evaluation.

In the literature, there are few papers that employ different MCDM approaches to evaluate WWT alternatives. Aragonés-Beltrán et al. [39] used AHP and PROMETHEE methods for the selection of WWT alternative. Bottera et al. [40] considered AHP and ANP for prioritizing different WWT technologies. Karimi et al. [41] presented the applications of AHP and fuzzy AHP for selecting the most appropriate WWT process. Sala-Garrido et al. [42] employed DEA for techno-economic efficiency comparison of different WWT technologies. Kalbar et al. [3] ranked WWT technologies used for the treatment of municipal wastewater in India by applying TOPSIS method. Srdjevic et al. [43] evaluated WWT methods for the metal industry in Serbia using AHP. Kalbar et al. [44] developed an MCDM approach that considered both qualitative and quantitative criteria for ranking WWT technologies. Gao and Fan [45] proposed a new MCDM method with attribute aspiration for ranking WWT alternatives. Kalbar et al. [46] compared the results of different MCDM methodologies used for ranking different WWT alternatives. Ouyang et al. [12] integrated fuzzy AHP and multidimensional scaling for determining the most appropriate natural WWT alternative. Molinos-senante et al. [48] used ANP for ranking WWT technology alternatives in small communities. Lately, Castillo et al. [49] developed an environmental decision support system to select the most suitable alternative for industrial wastewater

treatment in the food, drink and milk sector.

In this study, 2-tuple fuzzy linguistic representation model, linguistic hierarchies, DEMATEL method and TOPSIS method are integrated for identifying the most suitable WWT alternative. In fuzzy group decision making approaches, it is expected that decision makers provide their preferences using a set of previously determined linguistic variables. Because decision-makers have different cultural background and level of knowledge about the problem, they prefer to use non-homogeneous verbal terms with different degrees of uncertainty. The developed approach uses 2-tuple linguistic representation model and linguistic hierarchies to solve this problem. DEMATEL method is used to calculate the weights of the evaluation criteria. DEMATEL method does not require the unrealistic assumption of the mutual independence of criteria and it provides the calculation of the criteria weights by considering structural casual relationships of complex problems. In case of not using DEMATEL method, the weights of the criteria are determined either using subjective evaluations of decision-makers or weights will be considered equal. In this case, the interactions between the criteria will be ignored and therefore the problem will be unrealistic. DEMATEL ANP or AHP also consider the dependences among criteria but in order to use these methods, the criteria must have a hierarchical structure, which is not the case in our problem. In decision making process, humans strive to be both as close as possible to the ideal and as distant as possible from the anti-ideal, TOPSIS method, which is a distance-based MCDM technique, is used to rank the WWT alternatives. Other distance-based methods such as VIKOR and COPRAS can also be used, but VIKOR does not guaranty to provide complete ranking, and TOPSIS is the widely used method in the literature.

3. DEMATEL Method

The DEMATEL method is utilized for solving complicated and intertwined problems. It can be used to present the structural casual relationships of complex problems, and can be applied in various domains. DEMATEL methodology enables to consider interdependencies among criteria. The steps of DEMATEL method can be precised as follows [50].

Step 1. Construct the initial average matrix.

Decision-makers provide the direct influences among factor i and j, as indicated by a_{ij}. Then, the initial average matrix **A** is constructed. The diagonal elements of the average matrix are all set to zero, which means there is no influence by itself.

Step 2. Compute the initial influence matrix.

The initial influence matrix, **D**, is obtained by normalizing the average matrix as **D**=ξ**A**, where

$$\xi = \min\left[\frac{1}{\max_{1\le i\le n} \sum_{j=1}^{n}|a_{ij}|}, \frac{1}{\max_{1\le i\le n} \sum_{i=1}^{n}|a_{ij}|} \right] \tag{1}$$

Step 3. Derive the total influence matrix.

The total relation matrix **T** is defined as $T = D(I-D)^{-1}$, where **I** is the identity matrix. Let f and c as n x 1 and 1 x n vectors indicating the sum of rows and sum of columns of the total relation matrix **T**, respectively. Suppose f_i be the sum of ith row in matrix **T**, then f_i shows the total effects, both direct and indirect effects of factor i on the other factors. If c_j represents the sum of jth column in matrix **T**, then c_j states the sum of the direct and indirect effects that factor j has received from the other factors.

Step 4. Define a threshold value to obtain the digraph.

4. 2-Tuple Fuzzy Linguistic Representation Model

The 2-tuple linguistic model, composed by a linguistic term and a real number, was presented by Herrera and Martínez [16] to avoid the loss of information and improve the precision in processes of computing with words when the linguistic term set has an odd value of granularity, being triangular-shaped, symmetrical and uniformly distributed its membership functions [51]. It can be represented as (s_i, α) where s_i denotes the linguistic label of the described linguistic term set S_T, and α is a numerical value indicating the symbolic translation. The main advantage of the 2-tuple linguistic model is its computational model that offers linguistic results in the original linguistic domain in a precise way [51]. Moreover, it was proven that the linguistic computational model based on linguistic 2-tuples can avoid information distortion and loss [52].

Important definitions are given in the following to operate with the 2-tuples without loss of information.

Definition 1 [7]: Let $L = (\gamma_0, \gamma_1, ..., \gamma_g)$ be a fuzzy set described in S_T. A transformation function χ that transforms L into a numerical value in the interval of granularity of $S_T, [0, g]$ is given as

$$\chi : F(S_T) \rightarrow [0, g],$$

$$\chi(F(S_T)) = \chi\left(\{(s_j, \gamma_j), j = 0, 1, ..., g\}\right) = \frac{\sum_{j=0}^{g} j\gamma_j}{\sum_{j=0}^{g} \gamma_j} = \beta. \quad (2)$$

where $F(S_T)$ is the set of fuzzy sets defined in S_T.

Definition 2 [53]: Let $S = \{s_0, s_1, ..., s_g\}$ be a linguistic term set and $\beta \in [0, g]$ a value supporting the result of a symbolic aggregation operation, then the 2-tuple that expresses the equivalent information to β is obtained with the following function:

$$\Delta : [0, g] \rightarrow S \times [-0.5, 0.5),$$

$$\Delta(\beta) = \begin{cases} s_i, & i = \text{round}(\beta) \\ \alpha = \beta - i, & \alpha \in [-0.5, 0.5), \end{cases} \quad (3)$$

where 'round' is the usual round operation, s_i has the closest index label to 'β' and 'α' is the value of the symbolic translation.

Proposition 1 [53]: Let $S = \{s_0, s_1, ..., s_g\}$ be a linguistic term set and (s_i, α) be a 2-tuple. There is a Δ^{-1} function, such that, from a 2-tuple it returns its equivalent numerical value $\beta \in [0, g] \subset \Re$. This function is defined as

$$\Delta^{-1} : S \times [-0.5, 0.5) \rightarrow [0, g],$$

$$\Delta^{-1}(s_i, \alpha) = i + \alpha = \beta. \quad (4)$$

5. Linguistic Hierarchies

The concept of linguistic hierarchies was proposed by Cordon et al. [54] to design hierarchical systems of linguistic rules, then it was utilized to enhance precision of computing with words in the multi-granular linguistic information contexts [55]. A linguistic hierarchy is a set of levels, where each level is a linguistic term set with different granularity to the rest of levels of the hierarchy. Each level belonging to a linguistic hierarchy is denoted as $l(t, n(t))$, where t indicates the level of the hierarchy, and $n(t)$ is the granularity of the linguistic term set of the level t [20]. A linguistic hierarchy, LH, can be defined as the union of all levels t as $LH = \bigcup l(t, n(t))$.

The linguistic term set of level $t+1$ is obtained from its predecessor as [54]

$$L(t, n(t)) \rightarrow L(t + 1, 2.n(t) - 1) \quad (5)$$

Table 1 [56] shows the examples of the linguistic hierarchies.

Table 1. Linguistic hierarchies [56]

	Level 1	Level 2	Level 3	Level 4
$l(t, n(t))$	$l(1,3)$	$l(2,5)$	$l(3,9)$	$l(4,17)$
$l(t, n(t))$	$l(1,7)$	$l(,13)$		

Linguistic hierarchies are used to avoid the problem of loss of information that occurs in the unification phase of multi-granular linguistic information. The transformation function between linguistic terms in any level of the hierarchy is defined as

$$TF_t^{t'} : l(t, n(t)) \rightarrow l(t', n(t'))$$

$$TF_t^{t'}\left(s_i^{n(t)}, \alpha^{n(t)}\right) = \Delta\left(\frac{\Delta^{-1}\left(s_i^{n(t)}, \alpha^{n(t)}\right)\left(n(t') - 1\right)}{n(t) - 1}\right) \quad (6)$$

The transformation function is bijective, which guarantees the transformations are performed without loss of information [54].

6. Fuzzy Decision Making Algorithm

This section represents the fuzzy group decision making methodology, which is based on the TOPSIS method. TOPSIS determines the most appropriate solution based on simultaneous minimization of distance from the ideal solution and maximization of distance from the anti-ideal solution. In fuzzy multi-criteria group decision making problems, decision-makers are called to express their preferences on a predefined linguistic set. Since decision-makers have different cultural reasons and knowledge about the problem, they provide their preferences using different linguistic term sets with different granularity. This requires to unify all individual linguistic assessments into a basic linguistic term set. Multi-granular linguistic approaches can be employed to deal with this situation. The proposed methodology used linguistic hierarchies and 2-tuple fuzzy linguistic representation model to unify and aggregate multi-granular linguistic information provided by decision-makers without loss of information that occurs in the unification phase of multi-granular linguistic information. Moreover, it employs DEMATEL method to compute the weights of the criteria. DEMATEL method allows the consideration of inner dependencies among criteria. The developed approach that is illustrated in Figure 1 is represented below.

Step 1. Construct a decision-makers' committee of Z ($z=1,2,…,Z$) experts, and identify the alternatives ($i=1,2,…,m$) and required selection criteria ($j=1,2,…,n$).

Step 2. Construct the decision matrices for each decision-maker that denote the direct influence matrix among criteria and the ratings of alternatives with respect to criteria.

Step 3. Unify the multi-granular linguistic information given by the decision-makers into a linguistic term set employing Eq. (6).

Step 4. Aggregate the direct influence matrix and the ratings of alternatives using 2-tuple arithmetic mean operator as [57],

$$\bar{x} = \Delta\left(\frac{\sum_{i=1}^{n} \Delta^{-1}(s_i,\alpha)}{n}\right) \tag{7}$$

Step 5. Calculate β values of direct influence matrix and compute the importance weights of criteria, ψ_j, applying DEMATEL method.

Step 6. Compute the weighted ratings of alternatives as

$$v_{ij} = \psi_j \otimes r_{ij} \tag{8}$$

where r_{ij} is the β value of aggregated ratings of alternatives

Step 7. Determine the ideal solution $A^* = (v_1^*, v_2^*, \dots, v_n^*)$ and the anti-ideal solution $A^- = (v_1^-, v_2^-, \dots, v_n^-)$, where

$$v_j^* = \begin{cases} \left(\max_i v_{ij} \middle| j \text{ is a benefit criterion}\right) i = 1,2,\dots,m \\ \left(\min_i v_{ij} \middle| j \text{ is a cost criterion}\right) i = 1,2,\dots,m \end{cases} \tag{9}$$

and

$$v_j^- = \begin{cases} \left(\min_i v_{ij} \middle| j \text{ is a benefit criterion}\right) i = 1,2,\dots,m \\ \left(\max_i v_{ij} \middle| j \text{ is a cost criterion}\right) i = 1,2,\dots,m \end{cases} \tag{10}$$

for $j = 1,2,\dots,n$.

Step 8. Compute the distances from the ideal and the anti-ideal solutions (D_i^* and D_i^-, respectively) for each alternative as

$$D_i^* = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^*\right)^2}, \ i = 1,2,\dots,m; \ j = 1,2,\dots,n \tag{11}$$

$$D_i^- = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^-\right)^2}, \ i = 1,2,\dots,m; \ j = 1,2,\dots,n \tag{12}$$

Step 9. Calculate the ranking index (*RI*) of alternative i as follows:

$$RI_i = \frac{D_i^-}{D_i^- + D_i^+}, \ i = 1,2,\dots,m \tag{13}$$

Step 10. Evaluate the alternatives according to RI_i values in descending order.

7. Structure of the Wastewater Treatment Alternative Evaluation Problem and Experts Survey

Improving wastewater management and water quality are vital for sustainable development. Since, demand for water is growing at twice the rate of the population growth, without effective wastewater management strategies, development will be restricted.

For illustrating the application of the developed decision making method to WWT alternative selection, a case study organized in Istanbul is presented. As a result of discussions with experts, four WWT alternatives are determined as

A_1: Activated sludge,
A_2: Aerated lagoon,
A_3: Sequential batch reactor,
A_4: Constructed wetlands.

Eight criteria relevant to WWT alternative selection are identified as

C_1: Cost,
C_2: Global warming,
C_3: Eutrophication,
C_4: Land requirement,
C_5: Manpower requirement,
C_6: Reliability,
C_7: Sustainability,
C_8: Flexibility.

The assessment is conducted by a committee of four decision-makers (DM_1, DM_2, DM_3, DM_4). The linguistic hierarchy ,$LH=U/(1,3)$ shown in Figure 2 [24], is considered as multi-granular linguistic context, since the granularity of its linguistic term sets are very common in decision making problems.
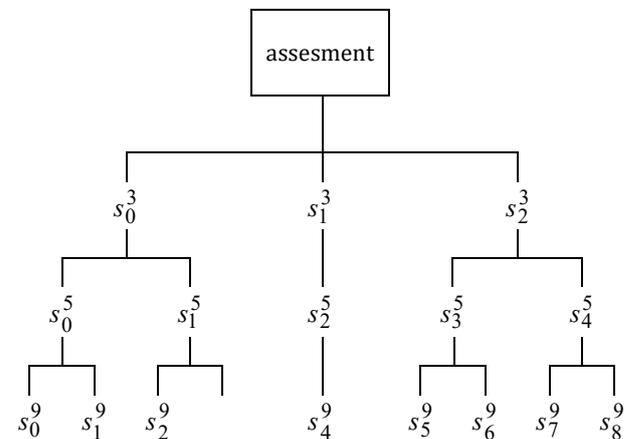

Fig. 2 The linguistic hierarchy [24]

DM_1 states his preferences in $l(1,3)$, DM_2 and DM_3 used $l(2,5)$, and DM_4 preferred to use $l(3,9)$. The assessments of four decision-makers are provided in Table 2 and 3.
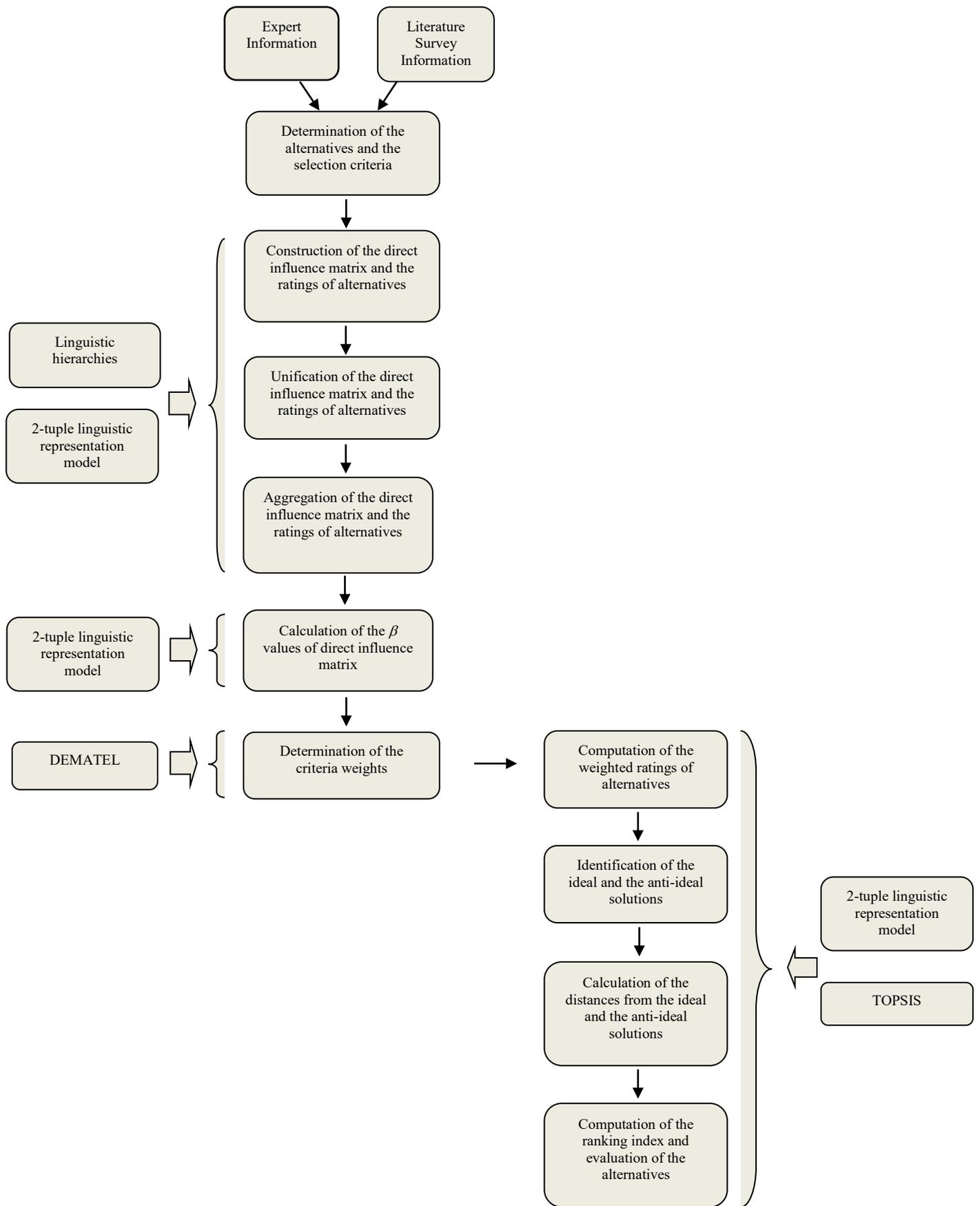
Fig. 1 Illustration of the proposed fuzzy decision making algorithm.

Table 2. Direct influence matrix among criteria

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
C_1		$(s_1^3, s_1^5, s_2^5, s_2^9)$	$(s_0^3, s_1^5, s_2^5, s_2^9)$	$(s_2^3, s_2^5, s_4^5, s_4^9)$	$(s_2^3, s_3^5, s_4^5, s_5^9)$	$(s_1^3, s_2^5, s_2^5, s_4^9)$	$(s_1^3, s_2^5, s_2^5, s_4^9)$	$(s_1^3, s_2^5, s_1^5, s_3^9)$
C_2	$(s_1^3, s_1^5, s_1^5, s_2^9)$		$(s_1^3, s_2^5, s_2^5, s_4^9)$	$(s_0^3, s_1^5, s_1^5, s_1^9)$	$(s_0^3, s_0^5, s_1^5, s_0^9)$	$(s_2^3, s_2^5, s_4^5, s_5^9)$	$(s_2^3, s_3^5, s_4^5, s_6^9)$	$(s_1^3, s_2^5, s_3^5, s_4^9)$
C_3	$(s_1^3, s_2^5, s_1^5, s_5^9)$	$(s_0^3, s_2^5, s_1^5, s_5^9)$		$(s_0^3, s_0^5, s_0^5, s_0^9)$	$(s_0^3, s_1^5, s_0^5, s_1^9)$	$(s_2^3, s_4^5, s_4^5, s_8^9)$	$(s_2^3, s_4^5, s_4^5, s_8^9)$	$(s_2^3, s_2^5, s_3^5, s_6^9)$
C_4	$(s_2^3, s_3^5, s_3^5, s_7^9)$	$(s_0^3, s_2^5, s_0^5, s_6^9)$	$(s_0^3, s_2^5, s_0^5, s_5^9)$		$(s_0^3, s_0^5, s_2^5, s_2^9)$	$(s_1^3, s_2^5, s_3^5, s_3^9)$	$(s_1^3, s_2^5, s_3^5, s_4^9)$	$(s_1^3, s_1^5, s_3^5, s_3^9)$
C_5	$(s_2^3, s_3^5, s_3^5, s_6^9)$	$(s_2^3, s_1^5, s_1^5, s_2^9)$	$(s_0^3, s_2^5, s_1^5, s_1^9)$	$(s_0^3, s_0^5, s_2^5, s_0^9)$		$(s_1^3, s_1^5, s_3^5, s_2^9)$	$(s_1^3, s_2^5, s_3^5, s_5^9)$	$(s_1^3, s_1^5, s_2^5, s_4^9)$
C_6	$(s_2^3, s_3^5, s_4^5, s_8^9)$	$(s_2^3, s_3^5, s_4^5, s_8^9)$	$(s_1^3, s_3^5, s_3^5, s_7^9)$	$(s_2^3, s_4^5, s_3^5, s_6^9)$	$(s_2^3, s_4^5, s_3^5, s_7^9)$		$(s_2^3, s_4^5, s_4^5, s_8^9)$	$(s_2^3, s_3^5, s_4^5, s_7^9)$
C_7	$(s_1^3, s_3^5, s_3^5, s_7^9)$	$(s_2^3, s_3^5, s_4^5, s_7^9)$	$(s_2^3, s_3^5, s_3^5, s_7^9)$	$(s_2^3, s_4^5, s_4^5, s_8^9)$	$(s_1^3, s_4^5, s_3^5, s_8^9)$	$(s_2^3, s_4^5, s_4^5, s_8^9)$		$(s_2^3, s_4^5, s_4^5, s_8^9)$
C_8	$(s_1^3, s_3^5, s_2^5, s_7^9)$	$(s_2^3, s_2^5, s_3^5, s_5^9)$	$(s_2^3, s_3^5, s_3^5, s_7^9)$	$(s_2^3, s_3^5, s_2^5, s_6^9)$	$(s_2^3, s_3^5, s_2^5, s_6^9)$	$(s_1^3, s_2^5, s_4^5, s_6^9)$	$(s_2^3, s_2^5, s_4^5, s_6^9)$	

Table 3. Ratings of alternatives with respect to criteria

	A_1	A_2	A_3	A_4
C_1	$(s_1^3, s_2^5, s_2^5, s_4^9)$	$(s_0^3, s_2^5, s_1^5, s_2^9)$	$(s_1^3, s_2^5, s_2^5, s_3^9)$	$(s_2^3, s_4^5, s_3^5, s_6^9)$
C_2	$(s_1^3, s_2^5, s_3^5, s_4^9)$	$(s_1^3, s_1^5, s_2^5, s_2^9)$	$(s_2^3, s_4^5, s_4^5, s_7^9)$	$(s_0^3, s_0^5, s_0^5, s_0^9)$
C_3	$(s_1^3, s_2^5, s_2^5, s_5^9)$	$(s_2^3, s_3^5, s_4^5, s_7^9)$	$(s_0^3, s_1^5, s_0^5, s_2^9)$	$(s_1^3, s_2^5, s_2^5, s_5^9)$
C_4	$(s_1^3, s_2^5, s_1^5, s_2^9)$	$(s_1^3, s_1^5, s_1^5, s_2^9)$	$(s_0^3, s_1^5, s_0^5, s_0^9)$	$(s_2^3, s_4^5, s_4^5, s_8^9)$
C_5	$(s_2^3, s_3^5, s_3^5, s_6^9)$	$(s_2^3, s_4^5, s_3^5, s_7^9)$	$(s_1^3, s_1^5, s_1^5, s_3^9)$	$(s_1^3, s_0^5, s_1^5, s_2^9)$
C_6	$(s_2^3, s_4^5, s_4^5, s_8^9)$	$(s_2^3, s_3^5, s_4^5, s_8^9)$	$(s_2^3, s_4^5, s_4^5, s_8^9)$	$(s_1^3, s_1^5, s_2^5, s_5^9)$
C_7	$(s_1^3, s_1^5, s_1^5, s_1^9)$	$(s_1^3, s_2^5, s_2^5, s_3^9)$	$(s_1^3, s_1^5, s_1^5, s_2^9)$	$(s_2^3, s_3^5, s_3^5, s_7^9)$
C_8	$(s_2^3, s_4^5, s_3^5, s_6^9)$	$(s_1^3, s_1^5, s_1^5, s_3^9)$	$(s_2^3, s_2^5, s_2^5, s_4^9)$	$(s_1^3, s_0^5, s_1^5, s_3^9)$

8. Results and Discussions

The linguistic term set l(2,5) is chosen as linguistic terms set to unify the multi-granular linguistic information provided by the decision-makers, since most of the decision-makers have expressed their preference in this linguistic term set. In the decision process, equal weights are assigned to decision-makers. Therefore, the unified assessments of decision-makers are aggregated employing 2-tuple mean operator, and the results are given in Table 4 and 5.

By employing DEMATEL method, the weights of criteria are determined as 0.1183, 0.1110, 0.1129, 0.1027, 0.1004, 0.1557, 0.1609 and 0.1380, respectively. C_1, C_2, C_4, and C_5 are considered as cost criteria, whereas C_3, C_6, C_7, and C_8 are considered as benefit criteria. The weighted ratings of alternatives are calculated employing Eq. (8).

Table 5. Ratings of alternatives with respect to criteria

	A_1	A_2	A_3	A_4
C_1	$(s_2, 0)$	$(s_1, 0)$	$(s_2, -0.125)$	$(s_4, -0.500)$
C_2	$(s_2, 0.250)$	$(s_2, -0.500)$	$(s_4, -0.125)$	$(s_0, 0)$
C_3	$(s_2, 0.125)$	$(s_4, -0.375)$	$(s_1, -0.500)$	$(s_2, 0.125)$
C_4	$(s_2, -0.500)$	$(s_1, 0.250)$	$(s_0, 0.250)$	$(s_4, 0)$
C_5	$(s_3, 0.250)$	$(s_4, -0.375)$	$(s_1, 0.375)$	$(s_1, 0)$
C_6	$(s_4, 0)$	$(s_4, -0.250)$	$(s_4, 0)$	$(s_2, -0.125)$
C_7	$(s_1, 0.125)$	$(s_2, -0.125)$	$(s_1, 0.250)$	$(s_3, -0.375)$
C_8	$(s_4, -0.500)$	$(s_1, 0.375)$	$(s_3, -0.500)$	$(s_1, 0.125)$

The distances from the ideal and the anti-ideal solutions for each alternative are calculated using Eqs. (9-12). Finally, the ranking index for each alternative is computed using Eq. (13). Table 6 resumes the results obtained employing the proposed methodology.

Table 6. Ranking of WWT alternatives

Alternatives	D_i^*	D_i^-	RI_i	Rank
A_1	0.5511	0.6181	0.5286	2
A_2	0.5035	0.6799	0.5745	1
A_3	0.6766	0.6183	0.4775	4
A_4	0.6939	0.6476	0.4827	3

According to the results of the analysis aerated lagoon is assessed as the most suitable WWT alternative, which is followed by activated sludge. Sequential batch reactor is ranked at the bottom due to high cost and global warming effect and low sustainability. The results obtained using the proposed method have been shared with experts and learned that the results will be considered in the future evaluations and will be shared with the necessary units. It is also planned to apply the developed decision making method in the future studies for the solution of group decision making problems, which should be applied to the opinions of decision makers with different experiences in the sectors of medicine (detection, diagnosis, treatment), digital marketing (evaluation of digital marketing tools) and energy (evaluation of sustainable energy alternatives).

This study employs DEMATEL method to calculate the weights of the criteria. DEMATEL method does not require the unrealistic assumption of the mutual independence of criteria and it provides the calculation of the criteria weights by considering structural casual relationships of complex problems. In case of not using DEMATEL method, the weights of the criteria are determined either using subjective evaluations of decision makers or weights will be considered equal. In this case, the interactions between the criteria will be ignored and therefore the problem will be unrealistic. Thus, conducting a sensitivity analysis by changing the weights is not realistic and it was ignored.

Table 4. Aggregated direct influence matrix among criteria

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
C_1		$(s_2, -0.5)$	$(s_1, 0)$	$(s_3, 0)$	$(s_3, 0.375)$	$(s_2, 0)$	$(s_2, 0)$	$(s_2, -0.375)$
C_2	$(s_1, 0.25)$		$(s_2, 0)$	$(s_1, -0.375)$	$(s_0, 0.25)$	$(s_3, 0.125)$	$(s_4, -0.5)$	$(s_2, 0.25)$
C_3	$(s_2, -0.125)$	$(s_1, 0.375)$		$(s_0, 0)$	$(s_0, 0.375)$	$(s_4, 0)$	$(s_4, 0)$	$(s_3, 0)$
C_4	$(s_3, 0.375)$	$(s_1, 0.25)$	$(s_1, 0.125)$		$(s_1, -0.25)$	$(s_2, 0.125)$	$(s_2, 0.25)$	$(s_2, -0.125)$
C_5	$(s_3, 0.25)$	$(s_2, -0.25)$	$(s_1, -0.125)$	$(s_1, -0.5)$		$(s_2, -0.25)$	$(s_2, 0.375)$	$(s_2, -0.25)$
C_6	$(s_4, -0.25)$	$(s_4, -0.25)$	$(s_3, -0.125)$	$(s_4, -0.5)$	$(s_4, -0.375)$		$(s_4, 0)$	$(s_4, -0.375)$
C_7	$(s_3, -0.125)$	$(s_4, -0.375)$	$(s_3, 0.375)$	$(s_4, 0)$	$(s_3, 0.25)$	$(s_4, 0)$		$(s_4, 0)$
C_8	$(s_3, -0.375)$	$(s_3, -0.125)$	$(s_3, 0.375)$	$(s_3, 0)$	$(s_3, 0)$	$(s_3, -0.25)$	$(s_3, 0.25)$	

9. Conclusions

Untreated wastewater has serious environmental and health hazards effects. Thus, wastewater must promptly be moved away from its sources and treated appropriately before final disposal. WWT alternative selection problem, which involves the consideration of vague and imprecise attributes, is a highly important group decision-making problem. The deterministic MCDM methods cannot effectively deal with decision making problems incorporating imprecise and linguistic information. This paper presents a fuzzy multi-criteria decision making algorithm, which combine 2-tuple fuzzy linguistic modeling, linguistic hierarchies, DEMATEL method and TOPSIS, to improve the problems gathered when using classical decision making method. The proposed method is apt to manage multi-granular linguistic information, and thus, provides the use of different semantic types by decision-makers. The main problem in aggregation of multi-granular linguistic information is the loss of information occurs in the unification process. The developed approach utilized 2-tuple linguistic information and linguistic hierarchies to deal with this problem.

The decision making procedure developed in this paper utilizes the transformation function between different levels of linguistic terms to unify the multi-granular linguistic information provided by the decision-makers. Besides, it considers 2-tuple mean operator as the aggregation operator, since equal weights are assigned to each decision-maker. Then, the unified information is converted into linguistic 2-tuples that enable using the principles of TOPSIS. The 2-tuple fuzzy linguistic approach and linguistic hierarchies inherit the existing characters of fuzzy linguistic assessment, and these approaches also deals with the problem of loss of information of other fuzzy linguistic approaches [25].

Future research might focus on applying the decision framework presented in here to real-world group decision making problems in diverse disciplines.

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