A Fuzzy Approach for the Assessment of Wastewater Treatment Alternatives

Mehtap Dursun

Abstract— **Wastewater management is seen as an important environmental problem faced by the developing countries. Untreated wastewater has serious effects on human health and natural environment. For this reason, selection of the appropriate wastewater treatment (WWT) alternative is vital for sustainable development. The aim of this paper is to propose a fuzzy multi-criteria decision making (MCDM) approach based on 2-tuple fuzzy linguistic representation model, decision making trial and evaluation laboratory (DEMATEL) method and fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method. The weights of criteria considered for alternative evaluation are calculated by decision making trial and evaluation laboratory (DEMATEL) method, and then fuzzy TOPSIS method is used to rank the alternatives. 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 application of the proposed methodology is illustrated through a case study for evaluation of wastewater treatment alternatives.**

Index Terms— **DEMATEL, multi-criteria decision making, TOPSIS, 2-tuple fuzzy linguistic representation, wastewater management.**

I. Introduction

TODAY, many countries suffer from persistent environmental problems and expect to encounter new problems in the future. Wastewater treatment is considered as one of the most important environmental problem faced by the developing countries as they strive to reduce waste, meet increasingly stringent wastewater consent conditions, and reduce total operating costs. Wastewater can be defined as the water supply of a community after it has been spoiled by use. It may contain human and household wastes, industrial wastes as well as groundwater and, in many cases, storm water runoff [1]. Before the wastewater can be safely returned to the environment, it must be treated. The aim of treatment is to reduce the level of pollutants in the wastewater before reuse or disposal into the environment [2].

Waste water treatment can involve physical, chemical or biological processes or combinations of these processes depending on the required outflow standards [3]. Different degrees of treatment levels are designated as preliminary, primary, secondary, and tertiary and/or advanced wastewater treatment.

Debris that could damage plant equipment is removed in the preliminary treatment plants. Primary settlement removes 90-95% of the settleable solids and is sometimes used prior to biological treatment. Secondary settlement separates the sludge solids from the outflow of the biological stage. Tertiary treatment refers to processes which are used to further reduce parameter values below the standards. Sludge treatment involves the stabilization and/or thickening and dewatering of sludge prior to reuse or disposal. It can be a significant part of a waste water treatment plant and [3].

According to the results of Municipal Wastewater Statistic Survey conducted in Turkey in 2010, out of 3.58 billion m3 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 m3 of wastewater discharged via sewerage, 2.72 billion m3 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% [4].

This paper focuses on the evaluation of WWT alternatives to determine the most appropriate one for Turkey. 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, 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. The weights of criteria are calculated by DEMATEL method, and then fuzzy TOPSIS method is used to rank the WWT alternatives.

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 2-tuple linguistic representation model that rectifies the problem of loss of information faced with other fuzzy linguistic approaches is employed in the

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M. Dursun is an Assistant Professor of Industrial Engineering, Galatasaray University, Ortakoy, Istanbul 34357, Turkey (fax: +90-212-259-5557; e-mail: mdursun@gsu.edu.tr).

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.

In the literature, there are few papers that employ different multi-criteria decision making (MCDM) approaches to evaluate WWT alternatives. Aragonés-Beltrán et al. [5] used analytic hierarchy process (AHP) and PROMETHEE methods for the selection of WWT alternative. Bottera et al. [6] considered AHP and analytic network process (ANP) for prioritizing different WWT technologies. Karimi et al. [7] presented the applications of AHP and fuzzy AHP for selecting the most appropriate WWT process. Sala-Garrido et al. [8] employed data envelopment analysis (DEA) for techno-economic efficiency comparison of different WWT technologies. Kalbar et al. [9] ranked WWT technologies used for the treatment of municipal wastewater in India by applying TOPSIS method. Srdjevic et al. [10] evaluated WWT methods for the metal industry in Serbia using AHP. Kalbar et al. [11] developed an MCDM approach that considered both qualitative and quantitative criteria for ranking WWT technologies. Gao anf Fan [12] proposed a new MCDM method with attribute aspiration for ranking WWT alternatives. Kalbar et al. [13] compared the results of different MCDM methodologies used for ranking different WWT alternatives. Ouyang et al. [14] inte-grated fuzzy AHP and multidimensional scaling for determining the most appropriate natural WWT al-ternative. Lately, Molinos-senante et al. [15] used ANP for ranking WWT technology alternatives in small communities.

The rest of the paper is organized as follows. In Section 2, basics of fuzzy sets are briefly introduced. Section 3 and Section 4 delineate the DEMATEL method and 2-tuple fuzzy linguistic representation model, respectively. Section 5 presents the stepwise representation of the proposed decision making approach. The implementation of the proposed methodology to WWT alternative selection problem is provided in Section 6. Finally, concluding remarks are given in the last section.

II. BASICS

Fuzzy set theory was formalized by Zadeh [16] to deal with problems in which a source of vagueness is involved. It has been utilized for incorporating imprecise data into the decision framework. A fuzzy set $\tilde{A}$ can be defined mathematically by a membership function $\mu_{\tilde{A}}(x)$, which assigns each element x in the universe of discourse X a real number in the interval [0,1].

A triangular fuzzy number $\tilde{A}$ can be defined by a triplet (a, b, c) as illustrated in Fig. 1.

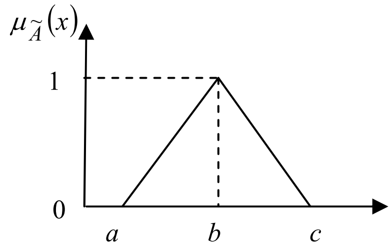

Fig. 1. A triangular fuzzy number $\tilde{A}$

Fusion approach of fuzzy information is proposed by Herrera et al. [17] and it provides a total flexible linguistic framework because of not impose any limitation related with the granularity of each linguistic term set as well as the shape of the fuzzy membership functions of each linguistic term [18].

It is performed in two phases as making the information uniform and aggregating individual preference values [17]. In the first phase, the multigranular information will be unified into a specific linguistic domain, called basic linguistic term set (BLTS) denoted as S_T, which is selected with the aim of keeping as much knowledge as possible.

The transformation function is defined as follows [17]: Let $\Omega = \{l_0, l_1, ..., l_H\}$ and $S_T = \{s_0, s_1, ..., s_G\}$ be two linguistic term sets, such that $G \geq H$. Then, the transformation function, τ_{AS_T}, is defined as

$$\begin{aligned} &\tau_{AS_T} : \Omega \to F(S_T), \\ &\tau_{AS_T}(l_h) = \left\{\left(s_g, \gamma_g^h\right) / \, g \in \{0,1,...,G\}\right\}, \quad \forall l_h \in \Omega, \\ &\gamma_g^h = \max_y \min\left\{\mu_{l_h}(y), \mu_{s_g}(y)\right\} \end{aligned} \tag{1}$$

where $F(S_T)$ is the set of fuzzy sets defined in S_T, and $\mu_{l_h}(y)$ and $\mu_{s_g}(y)$ are the membership functions of the fuzzy sets associated with the terms l_h and s_g, respectively.

In the second phase, the information expressed in multiple linguistic scales has been unified into fuzzy sets in the BLTS. This paper employs ordered weighted averaging (OWA) operator, initially proposed by Yager [19], as the aggregation operator.

Let $A = \{a_1, a_2, ..., a_n\}$ be a set of values to be aggregated, OWA operator F is defined as

$$F(a_1, a_2, ..., a_n) = \mathbf{w}\mathbf{b}^T = \sum_{i=1}^{n} w_i b_i \tag{2}$$

where $\mathbf{w} = \{w_1, w_2, ..., w_n\}$ is a weighting vector, such that $w_i \in [0,1]$ and $\sum_i w_i = 1$, and $\mathbf{b}$ is the associated ordered value vector where $b_i \in \mathrm{b}$ is the ith largest value in A.

The weights of the OWA operator are calculated using fuzzy linguistic quantifiers, which for a non-decreasing relative quantifier Q, are given by

$$w_i = Q(i/n) - Q((i-1)/n), \quad i = 1,...,n \quad (3)$$

The non-decreasing relative quantifier, Q, is defined as [13]

$$Q(y) = \begin{cases} 0 & , y < a, \\ \frac{y-a}{b-a} & , a \le y \le b, \\ 1 & , y > b, \end{cases} \quad (4)$$

with $a, b, y \in [0,1]$, and $Q(y)$ indicating the degree to which the proportion y is compatible with the meaning of the quantifier it represents. Some non-decreasing relative quantifiers are identified by terms 'most', 'at least half', and 'as many as possible', with parameters (a,b) are $(0.3,0.8)$, $(0,0.5)$, and $(0.5,1)$, respectively.

III. DEMATEL METHOD

The DEMATEL method is utilized to study and resolve complex social problems. It can be used to present the structural casual relationships of complex problems, and can be applied in various domains. Four major steps of DEMATEL method can be summarized as follows [20].

Step 1. Compute the average matrix.

Respondents are asked to indicate the direct influence that they believe each factor i exerts on each factor j of the others, as indicated by a_{ij}. From any group of direct matrices of respondents it is possible to derive an average matrix $\boldsymbol{A}$. The diagonal elements of the average matrix are all set to zero, which means no influence is given by itself.

Step 2. Calculate the normalized initial direct-relation matrix.

The normalize initial direct-relation matrix $\boldsymbol{D}$ can be obtained as $\boldsymbol{D}=\xi.\boldsymbol{A}$, where

$$\xi = \min\left[\frac{1}{\max_{1\le i\le n} \sum_{j=1}^{n} |a_{ij}|}, \frac{1}{\max_{1\le i\le n} \sum_{i=1}^{n} |a_{ij}|}\right] \quad (5)$$

Step 3. Calculate the total relation matrix.

The total relation matrix $\boldsymbol{T}$ is defined as $T = D(I-D)^{-1}$, where $\boldsymbol{I}$ is the identity matrix. Define f and c as n x 1 and 1 x n vectors representing the sum of rows and sum of columns of the total relation matrix $\boldsymbol{T}$, respectively. Suppose f_i be the sum of ith row in matrix $\boldsymbol{T}$, then f_i summarizes both direct and indirect effects given by factor i to the other factors. If c_j denotes the sum of jth column in matrix $\boldsymbol{T}$, then c_j shows both direct and indirect effects by factor j from the other factors. When $j = i$, the sum $(f_i + c_j)$ shows the total effects given and received by factor i. Thus, $(f_i + c_j)$ indicates the degree of importance for factor i in the entire system. On the contrary, the difference $(f_i - c_j)$ represents the net effect that factor i contributes to the system. Specifically, if $(f_i - c_j)$ is positive, factor i is a net cause; whereas factor i is a net receiver or result if $(f_i - c_j)$ is negative.

Step 4. Set up a threshold value to obtain the digraph.

In order to explain the structural relation among the factors while keeping the complexity of a system to a manageable level, it is necessary to set a threshold value to filter out some negligible effect in the total relation matrix.

IV. 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 [21] 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 [18]. It can be denoted as (s_g, α) where s_g represents the linguistic label of the predefined linguistic term set S_T, and α is a numerical value representing 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 [18].

The process of comparison between linguistic 2-tuples is carried out according to an ordinary lexicographic order as follows [22]:

Let $r_1 = (s_c, \alpha_1)$ and $r_2 = (s_d, \alpha_2)$ be two linguistic variables represented by 2-tuples.

- If $c < d$ then r_1 is smaller than r_2;
- If $c = d$ then
  - If $\alpha_1 = \alpha_2$ then r_1 and r_2 represent the same information;
  - If $\alpha_1 < \alpha_2$ then r_1 is smaller than r_2;
  - If $\alpha_1 > \alpha_2$ then r_1 is bigger than r_2.

In the following, we define a computational technique to operate with the 2-tuples without loss of information:

***Definition* 1 [23]:** Let $L = (\gamma_0, \gamma_1, ..., \gamma_G)$ be a fuzzy set defined 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 defined as

$$\chi : F(S_T) \to [0, G],$$

$$\chi(F(S_T)) = \chi(\{(s_g, \gamma_g), g = 0,1,..., G\}) = \frac{\sum_{g=0}^{G} g\gamma_g}{\sum_{g=0}^{G} \gamma_g} = \beta \quad (6)$$

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

***Definition* 2 [21]:** 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:

$$\Delta : [0, G] \rightarrow S \times [-0.5, 0.5),$$
$$\Delta(\beta) = \begin{cases} s_g, & g = \text{round}(\beta) \\ \alpha = \beta - g, & \alpha \in [-0.5, 0.5) \end{cases} \tag{7}$$

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

***Proposition* 1 [21]:** Let $S = \{s_0, s_1, ..., s_G\}$ be a linguistic term set and (s_g, 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

$$\Delta^{-1} : S \times [-0.5, 0.5) \rightarrow [0, G],$$
$$\Delta^{-1}(s_g, \alpha) = g + \alpha = \beta \tag{8}$$

V. FUZZY DECISION MAKING ALGORITHM

This section outlines the fuzzy MCDM approach, which is based on the fuzzy TOPSIS method [24]. TOPSIS, which is a widely accepted multi-attribute decision making technique, 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 [25]. The proposed methodology integrated 2-tuple fuzzy linguistic representation model and DEMATEL method to compute the weights of the criteria. The stepwise representation of the proposed fuzzy MCDM algorithm is given below.

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

Step 2. Construct the decision matrices for each decision-maker that denote the direct influence matrix among criteria, the fuzzy assessments corresponding to qualitative criteria and the crisp values corresponding to quantitative criteria for the considered alternatives.

Step 3. Let the fuzzy value assigned as the criterion e exerts on criterion j (j=1,2,…,n) and the rating of the pth alternative (p=1,2,…,P) with respect to the jth criterion for the zth decision maker be $\tilde{w}_{ejz} = (w^1_{ejz}, w^2_{ejz}, w^3_{ejz})$ and $\tilde{y}_{pjz} = (y^1_{pjz}, y^2_{pjz}, y^3_{pjz})$, respectively. Convert $\tilde{w}_{ejz}$ into the basic linguistic scale S_T. The importance weight vector on S_T, which is denoted as $F(\tilde{w}_{ejz})$, can be represented as

$$F(\tilde{w}_{ejz}) = (\gamma(\tilde{w}_{ejz}, s_0), \gamma(\tilde{w}_{ejz}, s_1), ..., \gamma(\tilde{w}_{ejz}, s_8)), \quad \forall j, z \tag{9}$$

In this study, the label set given in the following table is used as the BLTS [26].

TABLE I
LABEL SET [26]

Label set	Fuzzy number
s_0:	(0,0,0.12)
s_1:	(0,0.12,0.25)
s_2:	(0.12,0.25,0.37)
s_3:	(0.25,0.37,0.50)
s_4:	(0.37,0.50,0.62)
s_5:	(0.50,0.62,0.75)
s_6:	(0.62,0.75,0.87)
s_7:	(0.75,0.87,1)
s_8:	(0.87,1,1)

Step 4. Aggregate $F(\tilde{w}_{ejz})$ using OWA operator.

Step 5. Compute β values of $F(\tilde{w}_{ejz})$ and calculate the importance weights of criteria, ψ_j, by employing DEMATEL method.

Step 6. Aggregate $\tilde{y}_{pjz}$ using arithmetic mean operator.

Step 7. Normalize the ratings of alternatives to obtain unit-free and comparable sub-criteria values. If there exist crisp data y_{pj}, it can be represented as $\tilde{y}_{pj} = (y^1_{pj}, y^2_{pj}, y^3_{pj})$ in triangular fuzzy number format, where $y_{pj} = y^1_{pj} = y^2_{pj} = y^3_{pj}$. The normalized values regarding benefit ($j \in B$) as well as cost criteria ($j \in C$) are calculated employing linear scale transformation as

$$\tilde{r}_{pj} = \begin{cases} \left(\dfrac{y^1_{pj} - y^-_j}{y^*_j - y^-_j}, \dfrac{y^2_{pj} - y^-_j}{y^*_j - y^-_j}, \dfrac{y^3_{pj} - y^-_j}{y^*_j - y^-_j} \right), j \in B \\ \left(\dfrac{y^*_j - y^3_{pj}}{y^*_j - y^-_j}, \dfrac{y^*_j - y^2_{pj}}{y^*_j - y^-_j}, \dfrac{y^*_j - y^1_{pj}}{y^*_j - y^-_j} \right), j \in C \end{cases} \tag{10}$$

where $y^*_j = \max_p y^3_{pj}$, $y^-_j = \min_p y^1_{pj}$.

Step 4. Calculate the weighted normalized fuzzy decision matrix as

$$\tilde{v}_{pj} = \psi_j \otimes \tilde{r}_{pj} \tag{11}$$

Step 5. Define the ideal solution $\tilde{A}^* = (\tilde{v}^*_1, \tilde{v}^*_2, \ldots, \tilde{v}^*_n)$ and the anti-ideal solution $\tilde{A}^- = (\tilde{v}^-_1, \tilde{v}^-_2, \ldots, \tilde{v}^-_n)$, where $\tilde{v}^*_j = (1,1,1)$ and $\tilde{v}^-_j = (0,0,0)$ for $j = 1, 2, \ldots, n$.

Step 6. Calculate the distances from the ideal and the anti-ideal solutions(D^*_p and D^-_p, respectively) for each alternative as

$$D^*_p = \sum_{j=1}^{n} d(\tilde{v}_{pj}, \tilde{v}^*_j) \tag{12}$$

$$D_p^- = \sum_{j=1}^{n} d(\widetilde{v}_{pj}, \widetilde{v}_j^-) \quad (13)$$

where distance between two triangular fuzzy numbers $\widetilde{A} = (a_1, a_2, a_3)$ and $\widetilde{B} = (b_1, b_2, b_3)$ can be calculated as

$$d_v(\widetilde{A}, \widetilde{B}) = \sqrt{\frac{1}{3}\left[(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2\right]} \quad (14)$$

Step 10. Calculate the ranking index (*RI*) of the p th alternative:

$$RI_p = \frac{D_p^-}{D_p^- + D_p^*} \quad (15)$$

Step 11. Rank the alternatives according to RI_p values in descending order. Identify the alternative with the highest RI_p as the best alternative.

VI. EVALUATION OF WASTEWATER TREATMENT ALTERNATIVES

In order to illustrate the application of the proposed decision making method to WWT alternative selection, a case study conducted in Istanbul is presented. As a result of discussions with experts, four WWT alternatives are determined as

A_1: Activated sludge,
A_2: Upflow anaerobic sludge blanket followed by a facultative 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 evaluation of the direct influence matrix among criteria is conducted by a committee of five decision-makers (DM_1, DM_2, DM_3, DM_4, DM_5). DM_1, DM_2 and DM_3 used the linguistic term set with "very low (VL)", "low (L)", "moderate (M)", "high (H)", and "very high (VH)" as shown in Fig. 2, whereas the remaining three decision-makers, namely DM_4 and DM_5 preferred to use a different linguistic term set with "definitely low (DL)", "very low (VL)", "low (L)", "moderate (M)", "high (H)", "very high (VH)", and "definitely high (DH)" as depicted in Fig. 3.

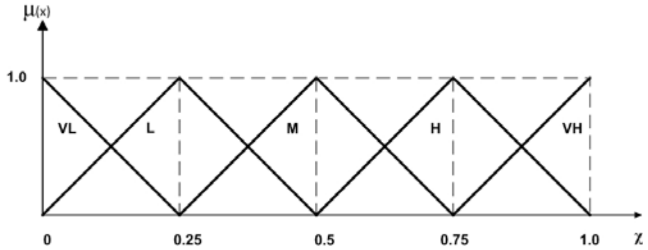

Fig. 2. A linguistic term set where VL: (0, 0, 0.25), L: (0, 0.25, 0.5), M: (0.25, 0.5, 0.75), H: (0.5, 0.75, 1), VH: (0.75, 1, 1).

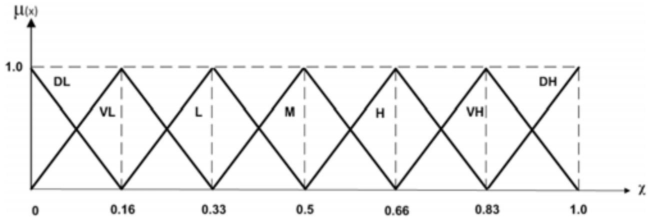

Fig. 3. A linguistic term set where DL: (0, 0, 0.16), VL: (0, 0.16, 0.33), L: (0.16, 0.33, 0.50), M: (0.33, 0.50, 0.66), H: (0.50, 0.66, 0.83), VH: (0.66, 0.83, 1), DH: (0.83, 1, 1)

The β values of the direct influence matrix among criteria are given in Table 3.

TABLE II
β VALUES OF THE DIRECT INFLUENCE MATRIX AMONG CRITERIA

	C1	C2	C3	C4	C5	C6	C7	C8
C_1	0.0000	3.5646	2.7803	6.1715	7.1312	4.0123	4.0123	3.9352
C_2	2.4323	0.0000	3.9474	1.5665	0.8703	6.1715	7.1312	5.1335
C_3	3.6346	2.7975	0.0000	0.6096	0.8703	7.4010	7.4010	5.8297
C_4	6.4323	2.1578	2.1578	0.0000	2.3894	4.4453	4.4453	3.9948
C_5	6.4323	1.5665	2.1936	2.2617	0.0000	4.0358	5.1335	4.0134
C_6	6.6184	7.1312	6.1983	6.1936	6.1936	0.0000	7.3411	7.1312
C_7	6.1983	7.1312	6.1983	7.3411	6.6184	7.4010	0.0000	7.4010
C_8	5.1335	5.5665	6.0311	5.5665	5.5665	6.0032	6.0032	0.0000

By employing DEMATEL method, the weights of criteria are determined as 0.1169, 0.0960, 0.0987, 0.0888, 0.0881, 0.1772, 0.1882 and 0.1462, respectively.

The ratings of alternatives are aggregated employing arithmetic mean operator. 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. Normalized ratings of alternatives are computed via Eq. (10). Then, employing Eq. (11), weighted normalized fuzzy decision matrix is constructed as in Table 3.

TABLE III
THE WEIGHTED NORMALIZED FUZZY DECISION MATRIX

	A_1	A_2	A_3	A_4
C_1	(0.088, 0.088, 0.088)	(0.117, 0.117. 0.117)	(0.097, 0.097, 0.097)	(0, 0, 0)
C_2	(0.037, 0.037, 0.037)	(0.065, 0.065, 0.065)	(0, 0, 0)	(0.096, 0.096, 0.096)
C_3	(0.046, 0.046, 0.046)	(0, 0, 0)	(0.099, 0.099, 0.099)	(0.054, 0.054, 0.054)
C_4	(0.030, 0.052, 0.074)	(0.037, 0.059,0.081)	(0.059, 0.081, 0.089)	(0, 0, 0.022)
C_5	(0, 0.022, 0.044)	(0, 0.007, 0.029)	(0.037, 0.059, 0.081)	(0.051, 0.073, 0.088)
C_6	(0.124, 0.177, 0.177)	(0.089, 0.142, 0.177)	(0.124, 0.177, 0.177)	(0, 0.053, 0.106)
C_7	(0, 0.051, 0.103)	(0.051, 0.103, 0.154)	(0, 0.051, 0.103)	(0.103, 0.154, 0.188)
C_8	(0.097, 0.134, 0.146)	(0.012, 0.049, 0.085)	(0.049, 0.085, 0.122)	(0, 0.024, 0.061)

The distances from the ideal and the anti-ideal solutions for each alternative are computed using Eqs. (12-14).

Finally, the ranking index for each alternative is computed using Eq. (15). Table 4 summarizes the results obtained using the fuzzy decision framework.

TABLE IV
RANKING OF WWT ALTERNATIVES

Alternatives	D_p^*	D_p^-	RI_p^*	Rank
A_1	7.4201	0.6099	0.0760	2
A_2	7.4618	0.5700	0.0710	3
A_3	7.3754	0.6523	0.0813	1
A_4	7.5439	0.4943	0.0615	4

According to the results of the analysis sequential batch reactor is determined as the most suitable WWT alternative, which is followed by activated sludge. Constructed wetlands are ranked at the bottom due to high cost, high land requirement, and low flexibility.

VII. CONCLUSIONS AND FUTURE WORK

Untreated wastewater has serious environmental and health hazards effects. Thus, wastewater must immediately be conveyed away from its generation sources and treated appropriately before final disposal. WWT alternative selection problem, which considers several individual attributes exhibiting vagueness and imprecision, may be regarded as a highly important group decision-making problem. The classical MCDM methods that consider deterministic or random processes cannot effectively handle decision-making problems including imprecise and linguistic information. In this paper, a fuzzy multi-criteria decision making algorithm, which combine 2-tuple fuzzy linguistic modeling, DEMATEL method and fuzzy TOPSIS, is proposed to rectify the problems encountered when using classical decision making methods in decision making problems. Future research might focus on applying the decision frameworks presented in here to real-world group decision making problems in diverse disciplines.

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