Evaluation of Wastewater Treatment Alternatives Using Fuzzy VIKOR Method

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***Abstract*—Recently, wastewater management is considered as one of the most important environmental problem faced by the developing countries. Untreated wastewater has serious effects on human health and natural environment. For this reason, this paper focuses on the evaluation of wastewater treatment alternatives. Fuzzy VIKOR method is proposed for identifying the most suitable wastewater treatment alternative. The computational procedure is illustrated through a case study conducted in Istanbul.**

***Index Terms*—Fuzzy MCDM, Fuzzy VIKOR, wastewater treatment**

I. INTRODUCTION

Continuing population growth and urbanization and rapid industrialization are diminishing water resources and increasing the unregulated discharge of contaminated water that presents a global threat to human health and wellbeing [1].

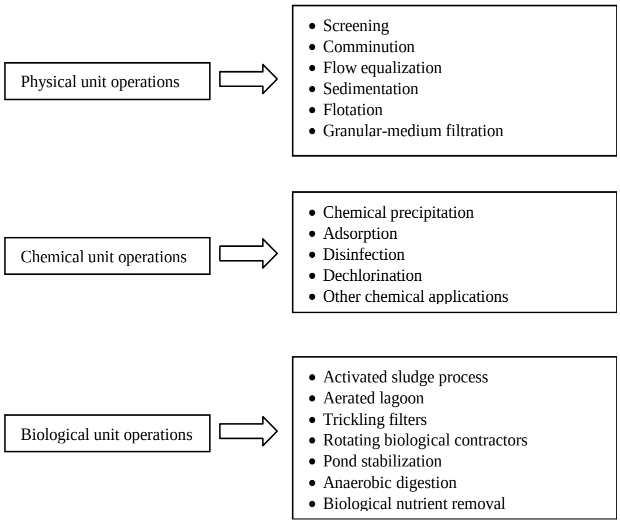

Figure 1. The unit operations included within each category [3].

Wastewater management has direct impact on the biological diversity of ecosystems, disrupting the fundamental integrity of life support system upon which a wide range of sectors from urban development, food production and industry depend. Therefore, wastewater must be considered as part of the integrated, ecosystem based management that operates across sectors and borders [2].

Wastewater treatment (WWT) is becoming more important due to scarce water resources and increasing wastewater disposal costs. Untreated wastewater generally contains high levels of organic material, numerous pathogenic microorganisms, as well as nutrients and toxic compounds. Thus, it must immediately be conveyed away from its generation sources and treated appropriately before final disposal [3].

The aim of wastewater management is the protection of the environment in a manner commensurate with public health and socio-economic concerns.

Increasing the speed of the natural purification process is seen as the basic function of the wastewater treatment plants. In earlier years, the natural treatment process in streams and lakes was adequate to perform basic wastewater treatment. As the population and industry grew, increased levels of treatment prior to discharging domestic wastewater became necessary [4]. Physical, chemical and biological methods are used to remove contaminants from wastewater. The unit operations included within each category are listed in Figure 1 [3]. In order to achieve different levels of contaminant removal, individual wastewater treatment procedures are combined into a variety of systems, classified as primary, secondary, and tertiary waste-water treatment [3]. The stages of wastewater treatment process are explained in Table I [5].

The aim of this paper is to evaluate WWT alternatives to determine the most suitable one. WWT alternative selection problem involves the consideration of conflicting criteria incorporating vagueness and imprecision. This study employs fuzzy VIKOR (VIseKriterijumska Optimizacija i kompromisno Resenje) for identifying the most suitable WWT alternative.

The rest of the paper is organized as follows. Section 2 delineates fuzzy VIKOR method. Section 3 presents the application of the fuzzy VIKOR methodology to WWT technology selection problem. The concluding remarks are given in the final section.

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TABLE I. STAGES OF WASTEWATER TREATMENT PROCESS [5].

Treatment Level	Description
Preliminary	Removal of wastewater constituents such as rags, sticks, floatables, grit, and grease that may cause maintenance or operational problems with the treatment operations, processes, and ancillary systems
Primary	Removal of a portion of the suspended solids and organic matter from the wastewater
Advanced primary	Enhanced removal of suspended solids and organic matter from the wastewater. Typically accomplished by chemical addition or filtration
Secondary	Removal of biodegradable organic matter (in solution or suspension) and suspended solids. Disinfection is also typically included in the definition of conventional secondary treatment
Secondary with nutrient removal	Removal of biodegradable organics, suspended solids, and nutrients (nitrogen, phosphorus, or both nitrogen and phosphorus)
Tertiary	Removal of residual suspended solids (after secondary treatment), usually by granular medium filtration or microscreens. Disinfection is also typically a part of tertiary treatment. Nutrient removal is often included in this definition
Advanced	Removal of dissolved and suspended materials remaining after normal biological treatment when required for various water reuse applications

II. FUZZY VIKOR

The VIKOR method has been developed as an MCDM method to solve a discrete multi-criteria problem with noncommensurable and conflicting criteria [6]. It focuses on ranking and selecting from a set of alternatives, and determines compromise solutions for a problem with conflicting criteria, which can help the decision makers to reach a final decision. The compromise solution is a feasible solution which is the closest to the ideal [7]. Opricovic [8] extended VIKOR in fuzzy environments to solve the problem of uncertainty in expressing DM's preferences. The stepwise representation of the fuzzy VIKOR method is as follows.

Step 1. Construct the fuzzy decision matrix and weight vector. Identify the alternatives (A_1, A_2,…,A_m) and required selection criteria (C_1, C_2,…, C_n).

$$\tilde{D} = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{bmatrix} C_1 & C_2 & \cdots & C_n \\ \tilde{f}_{11} & \tilde{f}_{12} & \cdots & \tilde{f}_{1n} \\ \tilde{f}_{21} & \tilde{f}_{22} & \cdots & \tilde{f}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{f}_{m1} & \tilde{f}_{m2} & \cdots & \tilde{f}_{mn} \end{bmatrix} \quad i = 1,2,\ldots,m;\ j = 1,2,\ldots,n.$$

$$\tilde{W} = \begin{bmatrix} \tilde{w}_1 & \tilde{w}_2 & \cdots & \tilde{w}_n \end{bmatrix}$$

where $\tilde{f}_{ij} = (l_{ij}, m_{ij}, r_{ij})$ indicates fuzzy performance rating of alternative A_i with respect to criterion C_j; and $\tilde{w}_j$ indicates the fuzzy weight for each criterion.

Step 2. Determine the fuzzy best $\tilde{f}_j^* = (l_j^*, m_j^*, r_j^*)$ and the fuzzy worst $\tilde{f}_j^- = (l_j^-, m_j^-, r_j^-)$ values for each criterion regarding benefit ($j \in B$) as well as cost criteria ($j \in C$).

$$\tilde{f}_j^* = \max_i \tilde{f}_{ij},\ \tilde{f}_j^- = \min_i \tilde{f}_{ij} \ \text{ for } j \in B \qquad (1)$$

$$\tilde{f}_j^* = \min_i \tilde{f}_{ij},\ \tilde{f}_j^- = \max_i \tilde{f}_{ij} \ \text{ for } j \in C \qquad (2)$$

Step 3. Compute the values $\tilde{S}_i$ and $\tilde{R}_i$, for i=1,2,…,m, by the relations

$$\tilde{S}_i = \sum_{j=1}^{n} \tilde{w}_j \left(\tilde{f}_j^* - \tilde{f}_{ij}\right) \Big/ \left(\tilde{f}_j^* - \tilde{f}_j^-\right) \qquad (3)$$

$$\tilde{R}_i = \max_j \left[\tilde{w}_j \left(\tilde{f}_j^* - \tilde{f}_{ij}\right) \Big/ \left(\tilde{f}_j^* - \tilde{f}_j^-\right)\right] \qquad (4)$$

Step 4. Compute the values $\tilde{Q}_i$, for i=1,2,…,m, as

$$\tilde{Q}_i = v \frac{\left(\tilde{S}_i - \tilde{S}^*\right)}{\left(\tilde{S}^- - \tilde{S}^*\right)} + (1-v) \frac{\left(\tilde{R}_i - \tilde{R}^*\right)}{\left(\tilde{R}^- - \tilde{R}^*\right)} \qquad (5)$$

where

$$\tilde{S}^* = \min_i \tilde{S}_i,\ \tilde{S}^- = \max_i \tilde{S}_i$$
$$\tilde{R}^* = \min_i \tilde{R}_i,\ \tilde{R}^- = \max_i \tilde{R}_i,$$

And v is defined as weight of the strategy of 'majority of criteria' (or 'the maximum group utility'), and $1\text{-}v$ is the weight of individual regret.

TABLE II. DATA RELATED TO WWT ALTERNATIVE SELECTION PROBLEM

	A_1	A_2	A_3	A_4	Weights of criteria
C_1	(M,M,H)	(M,L,L)	(M,M,M)	(VH,VH,VH)	(H,M,H)
C_2	(H,H,M)	(L,L,M)	(VH,VH,VH)	(VL,VL,VL)	(VH,H,VH)
C_3	(M,H,M)	(VH,H,H)	(L,VL,VL)	(M,H,L)	(VH,H,H)
C_4	(M,M,L)	(M,L,L)	(VL,L,VL)	(VH,VH,VH)	(H,M,M)
C_5	(H,H,H)	(VH,VH,H)	(M,L,L)	(L,VL,L)	(M,H,L)
C_6	(VH,VH,VH)	(H,H,VH)	(VH,VH,VH)	(M,L,M)	(VH,VH,VH)
C_7	(M,L,L)	(H,M,M)	(M,L,L)	(VH,H,H)	(VH,VH,VH)
C_8	(VH,VH,H)	(M,L,L)	(H,M,M)	(L,VL,L)	(H,H,VH)

Step 5. Rank the alternatives, sorting by the values S, R and Q, in ascending order. The results are three ranking list, with the best alternatives having the lowest value. Defuzzification of a triangular fuzzy number $\tilde{B} = (l_b, m_b, r_b)$ can be performed as follows [9]:

$$P(\tilde{B}) = \frac{(l_b + 4m_b + r_b)}{6} \quad (6)$$

Step 6. Propose a compromise solution, the alternative $\left(A^{(1)}\right)$, which is the best ranked by measure Q if the following two conditions are satisfied:

$C1$. 'Acceptable advantage': $Q\left(A^{(2)}\right) - Q\left(A^{(1)}\right) \geq DQ$, where $A^{(2)}$ is the alternative with second position in the ranking list by Q; $DQ = 1/(m-1)$ where m is the number of alternatives.

$C2$. 'Acceptable stability in decision making': The alternative $A^{(1)}$ must also be the best ranked by S or/and R. If one of these conditions is not satisfied, then a set of compromise solutions is proposed, consisting of:

- Alternatives $A^{(1)}$ and $A^{(2)}$ if only condition $C2$ is not satisfied, or
- Alternatives $A^{(1)}, A^{(2)}, \ldots, A^{(M)}$ if the condition $C1$ is not satisfied; $A^{(M)}$ is determined by the relation $Q\left(A^{(M)}\right) - Q\left(A^{(1)}\right) \geq DQ$ for maximum M.

III. CASE STUDY

As a result of discussions with experts, four WWT alternatives are determined as:

A_1: Activated sludge (AS),
A_2: Aerated lagoon (AL),
A_3: Sequential batch reactor (SBR),
A_4: Constructed wetlands (CWs).

Nine criteria relevant to WWT alternative selection are identified as

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

The evaluation of is conducted by a committee of five decision-makers (DM_1, DM_2, DM_3).The decision-makers used the linguistic term set depicted in Figure 2 to denote the ratings of alternatives with respect to criteria and the weights of each criterion as shown in Table II.

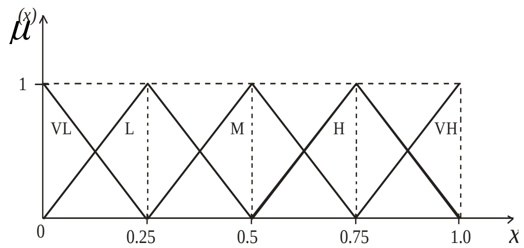

Figure 2. A linguistic term set where VL = (0, 0, 0.25), L = (0, 0.25, 0.5), M = (0.25, 0.5, 0.75), H = (0.5, 0.75, 1), VH = (0.75, 1, 1)

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 data obtained from decision makers are aggregated using arithmetic mean operator. The fuzzy best and fuzzy worst values of all criteria are computed employing Eq.(1) and Eq.(2), respectively. Then, the values for S, R and Q are computed employing Eqs.(3-5), respectively. In this study, the value of v is determined as 0.5. The results are given in Table III.

TABLE III. S, R AND Q VALUES FOR $v = 0.5$

	A_1	A_2	A_3	A_4
S	*2.792*	*2.370*	*2.527*	*3.560*
R	*0.978*	*0.660*	*0.971*	*1.043*
Q	*0.550*	*0.037*	*0.411*	*1.175*

The ranking of alternatives according to S and R values is obtained as $A_2 \succ A_3 \succ A_1 \succ A_4$. The ranking order according to Q value is obtained as $A_2 \succ A_3 \approx A_1 \succ A_4$. As condition C2 is not satisfied, a set of compromise is identified as A_3 and A_1. According to the results of the analysis, aerated lagoon is determined as the most suitable WWT alternative, which is followed by sequential batch reactor and aerated lagoon. Constructed wetlands are ranked at the bottom due to high cost, high land requirement, and low flexibility.

IV. CONCLUSIONS

Wastewater management requires effective water use, treatment, and disposal processes. Untreated wastewater has serious effects on human health and natural environment. Thus, wastewater management is considered as an important environmental problem faced by the developing countries. WWT alternative selection problem considers several individual attributes exhibiting vagueness and imprecision. To deal with the vagueness and imprecision inherent in the problem, this paper proposed the use of fuzzy VIKOR method. Future research might focus on comparing the results with those of different fuzzy MCDM techniques.

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