Evaluation of Water Treatment Technologies Using SAW-COPRAS Approach

MERT UNAL, MEHTAP DURSUN
Industrial Engineering Department
Galatasaray University
Cıragan Caddesi, No:36 34349, Ortakoy
TURKIYE

Abstract: - Providing safe and reliable water resources is an important issue. However, it becomes more and more complex problem due to rapid urban expansion and industrial growth. These challenges have led to the advancement of water treatment technologies. These technologies aim to enhance water quality and to optimize resource efficiency. Among the technologies that are frequently discussed in scholarly literature are membrane bioreactors, reverse osmosis systems, advanced oxidation processes, electrocoagulation techniques, granular activated carbon filtration, zero liquid discharge systems, and bio electrochemical treatment methods. Each of these technologies presents different advantages and they differ across several dimensions such as operational requirements, treatment efficacy, environmental implications, and financial considerations. Consequently, selecting the most suitable technology for a specific application requires evaluation of multiple criteria. Decision makers often have to balance technical performance with environmental impact, cost, and other practical concerns. To address this challenge, this study evaluates seven water treatment technologies employing a hybrid Fuzzy SAW–COPRAS approach. A set of relevant technical, environmental, and economic criteria is used to compare the selected technologies and determine their relative performance. The findings are expected to assist researchers, engineers, and policy makers in identifying suitable water treatment options.

Key-Words: - Fuzzy SAW; Fuzzy COPRAS; Fuzzy Logic; Water Treatment Technologies; Multi-Criteria Decision-Making; Technology Evaluation

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1 Introduction

Whether water is utilized for drinking, household use, food production, or recreational activities, it must be easily accessible and safe for the general public's health. Better management of water resources, along with better water supply and sanitation, can significantly reduce poverty and foster economic growth in nations. The increase in urbanization and industrialization as well as the erratic nature of climate change impacts the existing limited water sources. The impacts of unattended wastewater effluents discharge have also become a serious problem since it causes pollution of rivers, aquifers, seas etc. In these circumstances, water treatment has ceased being an activity involving only scientific processes but rather a foundation of sustainable growth and protection of public health [1], [2].

Classically, water treatment processes have been divided into three main categories: mechanical, biological, and physicochemical. Mechanical processes such as sedimentation, flotation, and filtration are used for the removal of suspended solids from raw water. Biological processes like activated sludge treatment, sequencing batch reactor treatment, biofilm reactor treatment, and anaerobic digestion treat raw water using microorganisms. Physicochemical processes, on the contrary, comprise adsorption, ion exchange, coagulation-flocculation treatment, advanced oxidation processes, and membrane treatment. In reality, treatment plants usually adopt a combination of various processes to adhere to tightly controlled water quality norms [3].

Over the last two decades, the need for higher-level solutions prompted the development of new technologies or hybrid technologies. The most investigated among them are Membrane Bioreactors (MBR), Advanced Oxidation Processes (AOPs), Electrocoagulation (EC), Granular Activated Carbon (GAC) adsorption, Zero Liquid Discharge (ZLD), Reverse Osmosis (RO) and Bio Electrochemical Treatment (BETT) technologies. MBR systems have been explored and have highlighted their high capability to remove pathogens and nutrients and are thereby considered suitable candidates for water reuse application [4]. Also, MBR has proven to produce good-quality effluents while minimizing sludge generation compared to conventional activated sludge systems [5]. For the AOPs, the efficiency of recent studies against pharmaceutical contaminants has proven to evaluate that hydroxyl radicals generated in such proc-esses can degrade compounds resistant to biological treatment [6]. Ganiyu et al. [7] attested to this by demonstrating that AOPs not only improve the removal of pollutants but also biodegradability of the treated effluent.

EC has also discussed by scholars. Bhagawati et al. [8] reviewed its applications. And they conclude that it has strong performance in removing oils, dyes, and heavy metals. However, problems with electrode consumption and sludge are still unresolved. Yet, Rajaniemi et al. [9] underlined that EC uses fewer chemical additives than traditional coagulation.

One of the oldest and still useful methods is granular activated carbon adsorption. According to Liao et al. [10], GAC is widely accessible and easy to operate. According to them, it is very effective at capturing trace organics and micropollutants. On the other hand, ZLD has become a key idea in industrial water management at the same time. After examining ZLD case studies, Panagopoulos and Giannika [11] came to the conclusion that although these systems are capable of recovering almost all wastewater as usable water, their capabilities are frequently constrained by expensive infrastructure and high energy requirements. Despite these developments, obstacles stand in the way of each technology's widespread use. MBRs need energy-intensive aeration and are vulnerable to membrane fouling [12]. AOPs require a significant amount of power and may produce secondary byproducts [13].

Because of these considerations, selecting the most suitable technology for a specific application requires evaluation of multiple criteria. Pawels and Tom [14] suggested that the selection of treatment options should not only be based on the efficiency of removal but also on considerations of energy use, environmental concerns, scalability, as well as long-term costs.

Multi-Criteria Decision-Making (MCDM) techniques have used in water treatment technology’s seleciton. Triantaphyllou [15] highlighted the importance of MCDM methods in comparison analysis, pointing out that they offer structured comparisons by combining a variety of qualitative and quantitative factors. In environments with limited resources and strong sustainability objectives, the function of MCDM in water treatment solutions becomes significant.

Based on this approach, this research proposes a hybrid Fuzzy decision-making approach combining Fuzzy SAW and Fuzzy COPRAS. The proposed approach examines and compares alternative water treatment technologies in a fuzzy environment. This helps in considering the vagueness of experts' opinions by using linguistic variables while preparing decisions. Firstly, Fuzzy SAW analysis determines the weight of the criteria based on opinions of three experts. Finally, Fuzzy COPRAS analysis determines the ranking of the similarity of the overall sustainability of the seven alternative water treatment technologies including MBR, AOPs, EC, ZLD, GAC, RO and BETT. The proposed approach has been found to bridge environmental, economic, as well as technical considerations. These considerations offer evidence-based decision-making capabilities in the context of sustainable water resources.

This study is organized as follows. Section 2 provides the research methodology. The application of the research methodology is represented in Section 3. Section 4 discusses the results. Lastly, conclusions are given in the last section.

2 Research Methodology

The methodology of the research work is structured to assess various water treatment technologies in an uncertain environment. For the assessment of various water treatment options in an uncertain environment, a combined approach of Fuzzy MCDM based on Fuzzy SAW and Fuzzy COPRAS techniques has been used. This approach not only provides a comprehensive analysis by assigning appropriate weights to certain criteria using Fuzzy SAW technique but also helps in ranking options based on overall performance by Fuzzy COPRAS technique.

First five key evaluation criteria—environmental impact (C_1), energy consumption (C_2), operating cost (C_3), technological maturity (C_4), and treatment efficiency (C_5)— are determined from both the literature search and expert consultation.

Three experts gave the linguistic evaluations. They explained them in fuzzy terms such as Very High (VH), High (H), Medium (M), Low (L), and Very Low (VL). From these linguistic evaluations triangular fuzzy numbers (TFNs) were created. Using fuzzy SAW method, the normalized fuzzy weights of each criterion were determined.

Using these weights and fuzzy COPRAS method, the seven water treatment technologies were assessed under five criteria. A clear ranking of the alternatives was obtained. The proposed research methodology is illustrated in Figure 1.

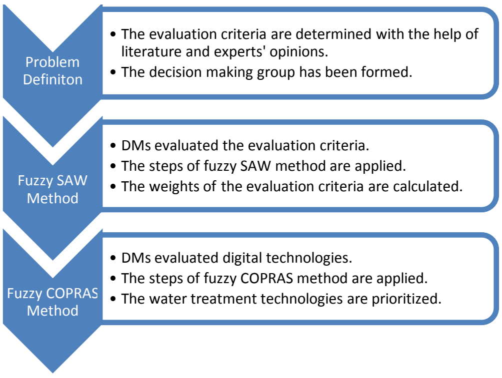

Fig. 1: The steps of the proposed research methodology

The following subsections explain Fuzzy SAW and Fuzzy COPRAS methods.

2.1 Fuzzy SAW Method

The Simple Additive Weighting (SAW) technique, developed by Hwang and Yoon [16]. This technique is one of the most widely applied MCDM method in the literature. Chou et al. [17] later extended this approach by introducing a fuzzy SAW model for facility location selection. The main steps of the fuzzy SAW method are outlined as follows:

Step 1. The criteria were assessed by the decision makers (DMs) based on the linguistic scale provided in Table 1.

Table 1. Fuzzy linguistic scale

Linguistic term	Abbreviation	TFN
Very Low	VL	(0.00, 0.00, 0.25)
Low	L	(0.00, 0.25, 0.50)
Medium	M	(0.25, 0.50, 0.75)
High	H	(0.50, 0.75, 1.00)
Very High	VH	(0.75, 1.00, 1.00)

Step 2. Each DM's relevance levels are reflected in the unequal DM weights. The importance degrees of DMs (I_t) are calculated:

$$I_t = \frac{d(\widetilde{w_t})}{\sum_{t=1}^{k} d(\widetilde{w_t})}, t = 1,2,\dots,k (1)$$

In this case, $d(\widetilde{w_t})$ represents the value of fuzzy weights.

Step 3. The weights of Cj which are illustrated as $\widetilde{W_j} = (a_j, b_j, c_j, d_j)$ are aggregated using Eq. (2)

$$\widetilde{W_j} = (I_1 \otimes \widetilde{W_{j1}}) \oplus (I_2 \otimes \widetilde{W_{j2}}) \oplus \dots \oplus (I_k \otimes \widetilde{W_{k1}}) (2)$$

Step 4. Defuzzification is performed for the fuzzy weight, denoted as $\widetilde{W_j}$, while its defuzzified value is represented by d $(\widetilde{W_j})$ as expressed below:

$$d(\widetilde{W_j}) = \frac{1}{4}\left(a_j + b_j + c_j + d_j\right), where\ j = 1, 2, \dots, n\ (3)$$

Step 5. The normalized values are calculated as follows:

$$W_j = \frac{d(\widetilde{w_j})}{\sum_{j=1}^{n} d(\widetilde{w_j})}, j = 1,2,\dots,n (4)$$

2.2 Fuzzy CORPAS Method

The Complex Proportional Assessment (COPRAS) method was first proposed by Zavadskas et al. [18] to prioritize alternatives based on their relative importance and utility. Subsequently, Zavadskas and Antucheviciene [19] extended the model by incorporating fuzzy logic for the evaluation of rural building regeneration options. The principal stages of the fuzzy COPRAS method are summarized as follows:

Step 1. The experts evaluated the alternatives using the linguistic scale presented in Table 1. The center of area (CoA) method was then applied to defuzzify the decision matrices, and the corresponding crisp values xij were obtained as follows:

$$x_{ij} = \frac{[(U_{x_{ij}} - L_{x_{ij}}) + (M_{x_{ij}} - L_{x_{ij}})]}{3} + L_{x_{ij}} (5)$$

Step 2. Each element of the decision matrix is normalized according to the following equation:

$$x_{ij}^{*} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} (6)$$

Step 3. The elements of the weighted normalized decision matrix are computed as follows:

$$d_{ij} = x_{ij}^{*} . w_j (7)$$

Step 4. The Si- and Si+ components representing the weighted standardized values are calculated according to the following expressions:

$$S_{i^{+}} = \sum_{j=1}^{k} d_{ij} (8)$$

$$S_{i^{-}} = \sum_{j=k+1}^{n} d_{ij} (9)$$

Step 5. The relative importance values (Qi) of the alternatives are determined as follows:

$$Q_i = S_{i^{+}} + \frac{\sum_{i=1}^{m} S_{i^{-}}}{S_{i^{-}} * \sum_{i=1}^{m} \frac{1}{S_{i^{-}}}} (10)$$

The most suitable alternative is the one exhibiting the highest relative relevance value.

Step 6. The Q_{max} value, representing the highest relative relevance score, is determined accordingly.

Step 7. The performance index (P_i) for each alternative is computed using the following equation:

$$P_i = \left[\frac{Q_i}{Q_{max}}\right] \times 100\% (11)$$

3 Application of Research Methodology

The Fuzzy SAW–COPRAS framework was applied to evaluate seven advanced water treatment technologies under real-world decision conditions. This section presents the application process step by step. It starts with the determination of criterion weights using the

Fuzzy SAW method. Then, Subsection 3.2 represents the prioritization of alternatives through the Fuzzy COPRAS method.

3.1 Calculating Criteria Weights Using Fuzzy SAW Method

To assess the evaluation criteria, three experts used the scale shown in Table 1. The corresponding evaluation matrix is presented in Table 2.

Table 2. Experts' evaluation for evaluation criteria

Criteria	**Expert 1**	**Expert 2**	**Expert 3**
Environmental Impact (C_1)	H	VH	M
Energy Consumption (C_2)	M	H	VH
Operating Cost (C_3)	M	M	VH
Technological Maturity (C_4)	VH	H	H
Treatment Efficiency (C_5)	VH	VH	H

Following this, the fuzzy SAW methodology was applied using formulations (1) – (4). The weights of evaluation criteria are provided in Table 3.

Table 3. Weights of evaluation criteria

Criteria	C_1	C_2	C_3	C_4	C_5
Weights	0.205	0.189	0.168	0.211	0.226

Results reveal that treatment efficiency and technological maturity are the most influential criteria. Energy consumption and operating cost were identified as the least important criteria.

3.2 Evaluating Water Treatment Technologies Using Fuzzy COPRAS Method

Initially, the scale presented in Table 1 was employed by the decision makers to evaluate the water treatment technologies. The experts' assessments of these technologies are summarized in Table 4.

Table 4. Experts' linguistic evaluations for alternatives

Alternatives	C_1	C_2	C_3	C_4	C_5
MBR	(H, VH, H)	(M, M, M)	(M, H, H)	(VH, VH, VH)	(VH, VH, VH)
AOP	(M, H, M)	(L, L, L)	(L, L, M)	(M, M, M)	(VH, H, H)
EC	(M, M, M)	(M, M, M)	(M, M, H)	(H, H, H)	(H, H, H)
ZLD	(VH, VH, VH)	(L, L, L)	(L, L, L)	(M, M, M)	(VH, VH, VH)
GAC	(H, H, H)	(H, H, H)	(H, H, H)	(VH, VH, VH)	(M, M, M)
RO	(M, M, M)	(L, M, L)	(L, L, M)	(H, H, H)	(VH, VH, VH)
BETT	(VH, VH, VH)	(H, H, H)	(M, M, M)	(L, M, L)	(M, M, M)

The fuzzy COPRAS method was then applied following the equations detailed in Section 2, and the resulting ranking of water treatment technologies is presented in Table 5.

Table 5. Ranking of the alternatives

Technology	Q_i	P_i	**Ranking**
MBR	3.634	100.0	1
ZLD	3.453	92.9	2
GAC	3.425	90.9	3
RO	3.161	87.5	4
EC	2.760	85.2	5
BETT	2.552	80.4	6
AOP	2.154	67.7	7

The Fuzzy COPRAS results indicate that the Membrane Bioreactor is the most suitable and balanced water treatment technology, showing strong performance in efficiency, maturity, and environmental aspects. ZLD and GAC follow. Technologies such as RO and EC perform moderately well but are limited by energy use and maintenance issues. BETT and AOP rank lower due to higher costs and lower technological maturity.

4 Results and Discussion

The integrated Fuzzy SAW – COPRAS analysis also provided an unequivocal ranking of the seven water treatment methods. Based on the defuzzification of the analysis output, it can be seen that overall effectiveness of the remaining six water treatment methods ranks MBR first. ZLD and GAC come next.

Technologies such as RO and EC received medium levels of scores due to high performance in the removal of pollutants. However, they lacked behind in terms of energy use and long-term maintenance. Technologies such as BETT and AOP received the lowest scores mainly due to increased costs and immaturity.

Analysis of the findings suggest that treatment efficiency and technological maturity are the most important criteria among the others. This confirms that the successful implementation of a water treatment system in practical conditions not only relies on its theoretical capabilities but also on its demonstrated ability to work properly in various conditions. As Judd [4] and Meng et al. [12] mentioned in their studies.

5 Conclusion

In this study, Fuzzy SAW and COPRAS methods were used to assess 7 key water treatment technolohies under 5 criteria. The model uses expert opinions together with a weighting and ranking system to compare the alternatives objectively under uncertain conditions.

The outcome presents MBR suitable water treatment technology due to its high performance in technological maturity and treatment efficieny. ZLD and GAC also scored highly, whereas AOP is listed as the worst due to its high operating cost and energy consumption.

The proposed framework is a transparent and adaptable tool for the selection of sustainable treatment technologies for municipal and industrial use. Rather than the ranking of alternatives, it provides decision-makers with a structured way of combining environmental, technical, and economic factors in line with international sustainability agendas such as SDG 6 and SDG 12.

Although the study was founded on a limited number of criteria and expert opinions, it shows the promise of fuzzy MCDM methods for evidence-based technology selection. Future studies can build upon this approach with more datasets, additional criteria such as life-cycle impacts, or a comparison with other fuzzy models.

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Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.