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Wastewater Treatment Technologies Selection Using Analytical Hierarchy Process and VIKOR Methods: A Case Study

Gnanasekaran Sasikumar*†, A. Sivasangari and S. Ravibabu***
* Department of Mechanical Engineering, GMR Institute of Technology, Rajam, Srikakulam District, 532 127, Andra Pradesh, India
**Department of Electronics and Communication Engineering, GMR Institute of Technology, Vizianagaram, Andhra Pradesh, India
†Corresponding author: Gnanasekaran Sasikumar; sasikumar.g@gmrit.edu.in

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ABSTRACT

Due to the ever-increasing water scarcity problem across the globe, the treatment of wastewater is an important public health and socio-economic issue. Treating wastewater through proper technology is vital to protect the ecosystem from unsafe and contaminated matter available in wastewater. Identification of suitable wastewater treatment technologies is a complex Multi-Criteria Decision Making (MCDM) problem since it includes many conflicting assessment criteria. The objective of the paper is to construct an integrated model using the Analytical Hierarchy Process (AHP) and VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) for evaluating wastewater treatment technologies (WWTTs). AHP is applied to calculate criteria weights, and the VIKOR method is applied to prioritize and select the best WWTTs. The proposed model is applied to selecting the best WWTT among four alternatives and seven criteria. It is found that the proposed model yields better results when compared with other MCDM solutions.

INTRODUCTION

Water treatment plants are constructed for efficient treatment of harmful and toxic elements found in wastewater to protect humans and the ecosystem. These plants are designed to process the wastewater to ensure the purification of water and its discharge to the environment. Due to the constant increase in the number of industries and people moving to cities, water contamination is becoming worse by the discharge of poisonous elements into water bodies. Additionally, growth in domestic and industrial activities increased the amount of wastewater that will be discharged to sewage systems. Hence, wastewater treatment is necessary to increase the availability of water.

AHP and Grey Relational Analysis methods were developed to compute criteria weights based on and rank the wastewater treatment technologies (Sasikumar et al. 2022). A combined AHP and ANP model is developed to evaluate WWTT performance (Bottero et al. 2011). Green and sustainable wastewater technologies are introduced by the investigators for wastewater treatment (Paruch et al. 2019). The discharge of heavy metals from industrial effluents of processing industries into the atmosphere has increased notably (Francis Xavier et al. 2022). The membrane and biological treatment methods are evaluated based on the removal of organic matter (Gutu et al. 2021). The implementation of natural coagulants to remove pharmaceutical products from water sources is discussed (Alazaiza et al. 2022). The AHP method is integrated with VIKOR to evaluate the performance of solar panels and rank them as per the performance score (Sasikumar et al. 2022, Sasikumar & Sivasangari 2022).

Many solutions for Agricultural recycling of water were suggested (Hidalgo et al. 2007). The fuzzy TOPSIS model is developed to evaluate wastewater treatment sites (Kim et al. 2013). Ranade and Bhandari (2014) proposed an industrial wastewater treatment by ELECTRE model. A fuzzy AHP model is recommended to rank optimal wastewater treatment and validated by empirical study (Ouyang et al. 2015). The application of DSS to choose proper wastewater treatment technology was described (Yahya et al. 2020). The AHP method was applied to choose the best Sewage Treatment Technology using thirteen selection criteria (Chaisar & Garg 2022). A model based on AHP and ANP is considered to prioritize the various technologies of wastewater treatment (Marta et al. 2011). An integrated decision-making approach by linear diophantine fuzzy sets is developed to decide on the best treatment technique (Samayan et al. 2022). A model based on the Choosing-by-advantages method is proposed to prioritize WWTTs and compare the results with AHP (Arroyo & Molinos-Senante 2018).

This paper is aimed to assess WWTTs to find out the most suitable one. WWTT selection problem contains many contradictory criteria, including ambiguity and fuzziness. This paper deals with the development of the AHP-VIKOR approach to identify the best WWTT choice.

COMBINED AHP-VIKOR MODEL FOR WASTEWATER TREATMENT TECHNOLOGIES (WWTTS) SELECTION

The selection of suitable WWTTs is an MCDM problem that can be selected by the VIKOR method. Firstly, the criteria AHP estimates weights, and VIKOR is applied to analyze and evaluate the WWTT options. Fig. 1 shows the WWTT selection by the proposed method:

APPLICATION OF AHP TO ESTIMATE CRITERIA WEIGHTS

The AHP is an MCDM technique that works on the Eigenvalue approach. It includes the standardization of numeric scales for measuring quantitative and qualitative performances. The scale covers the entire range of the comparison. The AHP offers a simple and ideally effective multi-criteria method to assess alternatives in a structured way considering contradictory multi-criteria involved in the selection.

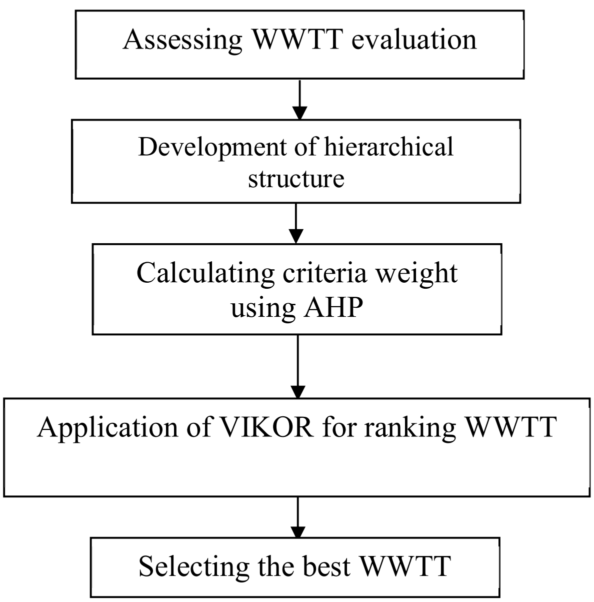

Fig. 1: Steps to be adopted for selection of best WWTT by VIKOR method.

This AHP model starts with the calculation of criteria weights that have the following phases:

Phase-1: Defining assessing criteria for selecting WWTTs

Phase 2: Determining an ordered structure by solving WWTT selection into an order of organized decision domains

Phase-3: Determining the pairwise comparison matrix A_P using the following procedure:

All evaluators build a pairwise comparison of elements and assign comparative scores. C_1, C_2, ..., C_n Indicates criteria, while a_{ij} denotes a calculated decision on a set of criteria C_i and C_j. The relative importance of two factors is evaluated by a scale as shown in Table 1 (Saaty 2000) and shown as matrix A_P as presented in equation 1:

$$A_P = [a_{ij}] = \begin{array}{c} \\ C_1 \\ C_2 \\ \vdots \\ C_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix} \end{array} \quad \ldots(1)$$

Where a_{ij} is equal to one and a_{ij} is the reciprocal of a_{ij}.

Phase-4: Calculating the weight of pairwise comparison matrix by additive normalization technique for arriving priority vector w. It is calculated by dividing all column elements of A by the total of columns, later summing up the elements of all resulting rows, and lastly dividing the value by a number of rows.

Phase-5: Checking the consistency of the comparison matrix by equations 2 and 3.

Saaty (1980, 2008) has used consistency index (CI) and Eigenvalue (λ_{max}) to compute the consistency ratio (*CR*), which is presented below:

$$\text{Consistency index} = (\lambda_{max}\text{-m})/(\text{m-1}) \quad \ldots(2)$$

$$\text{Consistency ratio= Consistency index/Random index} \ldots(3)$$

Where m represents matrix size, the random index is chosen from Table 1. The *CR* is suitable if it is not more than 0.10. It becomes inconsistent if CR is greater than 0.10. In order to get consistency, judgments will be examined continuously Saaty (1980).

Phase-6: Aggregating the comparative scores by Geometric mean method.

VIKOR METHOD

The VIKOR method was established by Opricovic & Tzeng

Table 1: Random Index values.

Matrix dimension	1	2	3	4	5	6	7	8	9	10
Random consistency	0	0	0.6	0.9	1.1	1.2	1.3	1.4	1.45	1.5

(2004 & 2007) to resolve MCDM problems with ambiguous and disproportionate criteria. It assumes that compromise is tolerable for resolving conflict, a solution that is closest to the ideal. In the VIKOR approach, alternative ranking is obtained based on the regret value of each alternative, which has inconsistent criteria. VIKOR method focuses on resolving a possible solution nearest to the ideal solution. VIKOR provides a maximum group utility of the majority and a minimum of the individual regret of the opponent. VIKOR method is applied in Design and manufacturing management, Business and marketing management, Environmental resources and energy management, Supply chain management, Construction management, and risk management. The ranking is done based on the criteria weights obtained by AHP, and the VIKOR method is used for discrete choice issues with conflicting standards by trade-off positioning strategy based on distinguishing the quantity of closeness with best choices.

The computational steps in VIKOR are stated as follows:

Stage-1:
Compute the best and worst $(f_i^+ \ \& \ f_i^-)$ scores of criterion functions, i = 1,2,...,n; f_i^+ = max (f_{ij}), f_i^- = min (f_{ij}), j=1,2...,j). If i^th^ function is beneficial, then f_i^+ = max (f_{ij}) and f_i^- = min (f_{ij}), j=1,2...,j) . If i^th^ function is cost, then f_i^+ = min (f_{ij}) and f_i^- = max (f_{ij}).

Stage-2:
Calculation of S_j and R_j, j=1,2,...,j, using Equations 4 and 5:

$$S_j = \sum_{i=1}^{n} w_i (f_i^+ - f_{ij})/(f_i^+ - f_i^-) \quad \ldots(4)$$

$$R_j = \max\,[w_i (f_i^+ - f_{ij})/(f_i^+ - f_i^-)] \quad \ldots(5)$$

where w_i Indicates criteria weights.

Stage-3: Estimation of Q_j by equation 6:

$$Q_j = [v\frac{(S_j - S^*)}{(S^- - S^*)}] + [\ (1-v)\frac{(R_j - R^*)}{(R^- - R^*)}] \quad \ldots(6)$$

where S^* = min (S_j), S^- = max (S_j), j=1,...,j), R^* = min (R_j), R^- = max (R_j), j=1,...,j),; and k and (1-k) represent the weight of maximum group utility and individual regret, respectively. k varies from 0 to 1.

Stage-4: Grading the options by classification of S, R, and Q from smallest value.

Stage-5: Proposing a compromise solution the alternative A1, which is the best ranked by the measure Q (minimum) on satisfactory fulfillment of the below condition:

C1. "Acceptable Advantage": Q (A2) – Q (A1) ≥ 1/(N-1), A2 is the alternative with second position by Q;

C2. "Acceptable Stability in decision making": The alternative A1 should also be the greatest ranked by S or/and R. This compromise solution is found to be good for the MCDM problem. (Opricovic & Tzeng 2004, 2007).

CASE STUDY

The integrated AHP and VIKOR methods deal with the implementation of the AHP method to get the criteria weights by different evaluators, followed by the application of the VIKOR method to evaluate and compare the performance of four wastewater treatment technologies and seven parameters, namely manpower requirement, Durability, Aesthetics, Power consumption, Removal Efficiency,

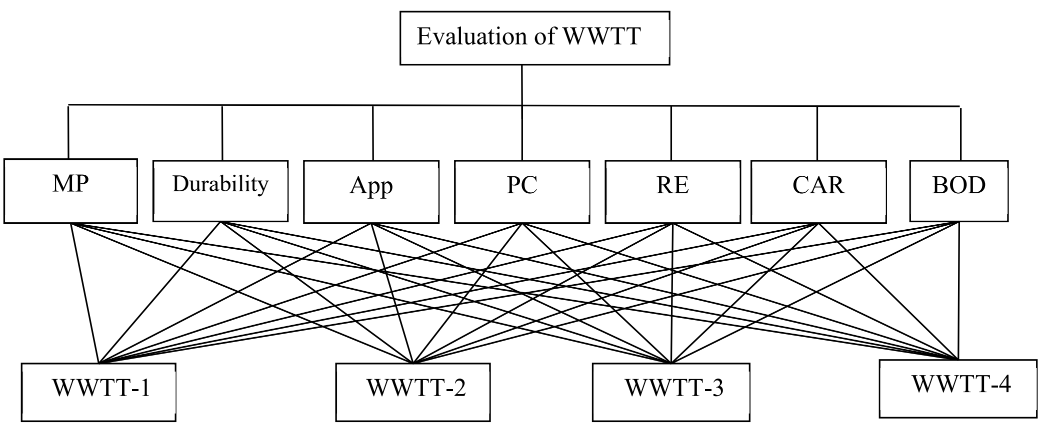

Fig. 2: Combined AHP-VIKOR model for WWTT selection.
MPR-Manpower requirement, D-Durability, App-Aesthetics, PC- Power consumption, RE-Removal Efficiency, CAR- Construction area requirement and BOD- Biochemical Oxygen Demand

Table 2: Salty's 9- Point Scale.

Amount of comparative importance	Description of importance
1	Identical
3	Low
5	High
7	Very high
9	Absolute
2,4,6,8	Intermediate values

Construction area requirement, and Biochemical Oxygen Demand.

Fig. 2 depicts the proposed AHP-VIKOR model for WWTTs selection.

Applying AHP for Calculating Criteria Weights

The AHP is started by interviewing the decision makers and taking their inputs for pairwise comparison. To simplify the evaluation process, a program is written in EXCEL to compute the weights. The judgment matrix size is 7×7, and its consistency ratio is computed as 0.07, which is less than 0.1, which shows the consistency of the judgment matrix. The AHP is applied to find out the criteria weight. Table 2 shows Saaty's 9-point scale (Saaty 2000).

The criteria weights are estimated by the method explained in this section, and the details are given in Table 3.

As shown in Table 3, it is evident that BOD has higher importance than other criteria in WWTTs ranking. The data on four alternative WWTTs with respect to eight criteria are collected and shown in Table 4.

Application of the VIKOR Method

Step 1: Computation of best f_i^+ and worst f_i^- values of all criterion functions, i = 1,2,...,n; $f_i^+ = \max(f_{ij}, j=1,...,J)$, $f_i^- = \min(f_{ij}, j=1,...,J)$. Among the seven criteria for WWTT selection, Durability, manpower, Aesthetics, Removal Efficiency, and BOD are considered beneficial criteria that higher values are assigned. Power consumption and CAR are non-beneficial criteria, and lesser values are assigned, as depicted in Table 5.

Table 3: Criterion weights for WWTTs selection.

Criteria	MPR	Durability	APP	Power consumption	Removal Efficiency	CAR	BOD
Weight	0.13	0.16	0.05	0.14	0.22	0.04	0.26

Table 4: Alternatives and criteria for WWTTs.

WWTT	MPR	Durability	APP	Power consumption	Removal Efficiency	CAR	BOD
AS	2	5	5	3	87	0.4	88
WSPs	5	3	3	4	83	0.46	86
CWs	1	2	4	5	91	0.5	83
MBR	4	1	5	3	82	1.4	81

Table 5: Best f_i^+ and the worst f_i^- values.

Parameter	MPR	Durability	APP	Power consumption	Removal Efficiency	CAR	BOD
f_i^+	45	220	5	3	90	0.3	90
f_i^-	0.8	20	4	4	80	1.2	80

Table 6: Values of S_j and R_j.

WWTT	1	2	3	4	5
S_j	0.695	0.292	0.789	0.105	0.389
R_j	0.270	0.156	0.186	0.075	0.171

Table 7: Values of Q_j for different k values.

k	WWTT1	WWTT2	WWTT3	WWTT4
0	0	0.0716	0.3368	1
0.2	0	0.2212	0.3513	1
0.4	0	0.3708	0.3656	1
0.6	0	0.5204	0.3800	1
0.8	0	0.6700	0.3945	1
1	0	0.8196	0.4089	1

Step 2: Calculation of S_j and R_j, j=1,2,...,J, using equations 4 and 5 (Table 6).

Step 3: Computation of Q_j for various k values

The values of Q_j for k=(0 to 1) are computed by equation 6, and Table 7 shows the Q_j values.

Step 4: Rank the WWTTs by arranging S, R, and Q from the minimum value

"Acceptable Advantage": Q (A2) – Q (A1) ≥ 1/ (N-1), A2 is the alternative with second position in the ranking list by Q

Ranking the WWTTs by the proposed AHP-VIKOR method, Q (S3) – Q (S1) = 0.3656-0 = 0.3656 ≥ 1/ (4-1) = 0.3656 ≥ 0.33 (here, N=4)

The WWTT 4 is best ranked by Q, and conditions C1 and C2 are satisfied as this alternative is also best ranked by S and R and Q (S3) – Q (S1) ≥ 1/(N-1).

The final ranking of WWTTs is WWTT1> WWTT3> WWTT2> WWTT4.

The final ranking of WWTTs is shown in Table 7 for the corresponding Q_j And k (k varies from 0 to 1). WWTTs 1 and 3 are better than other WWTTs (2 and 4). With subsequent consideration of other criteria, it is concluded that WWTT1 is evaluated better than the other three WWTTs.

CONCLUSION

The selection of wastewater treatment technology includes both subjective and objective criteria, which makes the problem a complex MCDM problem. Choosing the suitable wastewater treatment technology is a key factor for optimizing the wastewater treatment process by the following factors:

- A number of criteria
- Contradictory criteria
- Availability of various alternatives

The AHP-VIKOR model is developed for the selection of WWTTs by computing criteria weights using the AHP method and ranking of WWTTs by the VIKOR method. The criteria considered in the model are Workforce requirement, Durability, Aesthetics, Power consumption, Removal Efficiency, Construction area requirement, and Biochemical Oxygen Demand.

Based on the case study, it is found that BOD has more weight vector and has more importance than other criteria. It is observed that WWTT 1 is preferred over the remaining WWTTs.

The proposed model has the following features for WWTT selection:

(i) The model computes the weights of the criteria efficiently.

(ii) Subjective evaluation of intangible sub-criteria is removed.

(iii) The model considers the comparative value of the criteria

(iv) The VIKOR gives better results than other MCDM methods

The results of the AHP-VIKOR method shall be compared with the results of other methods in terms of the calculation of the weights and their utilization for selection and ranking. In addition to WWTTs, the AHP-VIKOR method is suitable for other MCDM problems. To simplify the calculation procedure of the AHP-VIKOR model and obtain faster results, a decision support system can be developed.

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