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MULTI-CRITERIA EVALUATION OF ADVANCED DRINKING WATER TREATMENT TECHNOLOGIES USING ANALYTIC HIERARCHY PROCESS (AHP) AND TECHNIQUE FOR ORDER OF PREFERENCE BY SIMILARITY TO IDEAL SOLUTION (TOPSIS)

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Abstract
How to render unsafe water potable is a chief priority for most governments and people. This has brought about the evolution of water treatment technologies. This article provides a review of these technologies and the criteria for selecting them, and uses the multi-criteria decision making (MCDM) approach to rank each set and select the best technology and the most important criterion. It employed two MCDM methods to quantitatively evaluate ten water treatment technologies with regard to ten criteria for selection. Data were obtained from available literature and applied to analyze the technologies and assess the effect of the criteria on them in any location under the same circumstances by pairwise comparison. The technologies were rated against the criteria on a 5-point Likert scale. The absolute values obtained were used to generate relative ones by comparing the technologies and the criteria on Saaty's 9-point Scale of Relative Importance. Pairwise comparison matrices were formed and weighted. A global matrix was computed from which the final rankings were obtained. AHP ranked electrodialysis highest, followed by electrodialysis reversal while TOPSIS ranked ion exchange technology highest, followed by electrodialysis reversal. For the criteria, economy and efficiency were found to be the most influential while legal aspects was the least. This means that electrodialysis reversal is the best among the ranked technologies with regard to the criteria for selection considered while economy and efficiency are the most important criteria. Hence, the study proposes electrodialysis reversal for municipal, commercial and private water treatment.

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1.0 INTRODUCTION
Less than 1% of the earth's freshwater is accessible to man [1]. Globally, up to 780 million people which represent over 10% of the world population do not have access to safe, improved drinking water [2]. It is estimated that, without action, global demand for freshwater will be one-third greater than it is now by 2050 [3].

This danger is accentuated by water polluters which include agricultural practices, improper sewage and wastewater disposal, oil pollution, and radioactive substances. Pollution from these sources takes heavy toll on human health and the environment; cases of which are Legionnaires' disease and eutrophication respectively [4].

Water with impurities causes diseases like cholera, giardia, dysentery, and typhoid fever to humans. Additionally, it causes difficulty in lathering of soap, furring of boilers and kettles, unwanted growth on plumbing fittings which can lead to eventual blockage, and adversely affects the stages of dyeing and tanning [5]. Hence, the need to treat water.

The chief aim of drinking water treatment is to produce safe and attractive water, and to prevent corrosion, buildup of solids, and bacterial growth in the transport and distribution network [6]. This must be done at optimal conditions with minimal costs and impact on the environment [7].

AHP and TOPSIS have been applied in various real-world multi-criteria decision analysis (MCDA) problems [8]. Banigo Amy applied them in 2012 to rank water supply sources in Nigeria, using ten criteria and six options. She arrived at quality being the most influential criterion and borehole being the best source of water in Nigeria. Nnaji and Banigo applied them to rank sources for self-help domestic water [9].

Similarly, Ankon *et al* applied them to assess the sustainability of water supply projects based in communities [10]. Srdjevic *et al* applied them to evaluate wastewater treatment technologies in constructed wastelands [11]. Prieto-Jimenez *et al* applied them to select rainwater harvesting systems in some rural areas [12]. Han *et al* applied TOPSIS and fuzzy TOPSIS for the evaluation of sustainable water management strategies [13]. Nedjar *et al* applied AHP to plan the rehabilitation of water distribution networks [14].

For the first seventy-five years of the past century, induced clarification, physical filtration, and disinfection were almost the only treatment processes applied in municipal water treatment [15]. However, the last half-century has witnessed a drastic change in the approach of the water industry to water treatment giving rise to water utilities seriously considering alternative treatment methods different from the conventional filtration-disinfection. [16].

More recent technologies and methods such as ion exchange, microfiltration, ultrafiltration, nanofiltration, electrodialysis, electrodialysis reversal, electrodeionization, desalination, reverse osmosis and forward osmosis are able to remove more complex and diverse range of contaminants, thus guaranteeing safer drinking water. This study analyzes ten water treatment technologies and examines the effect of ten criteria for selection on these technologies using MCDM methods.

2.0 METHODOLOGY

The evolution and application of technologies for treating water have been majorly dictated by three fundamental factors: cost, the promulgation of new standards for water quality, and the finding out of new contaminants [17]. These technologies as used in this work are briefly described in Table 1.

One of the most important decisions in water treatment is the choice of technology to use under a given set of conditions for optimal performance in saving cost, time, resources, as well as minimization of negative impacts. For the purpose of this study, a wide range of potential environmental, socio-economic and technical factor were used as MCDM criteria. Legality and ease of operation and maintenance are some issues for concern here [18].

The ten criteria considered are technology requirement, energy requirements, health impact, environmental impact, economy, ease of operation and maintenance, treatment versatility, legal aspects, quantity requirement and efficiency. These are briefly discussed in Table 2.

Based on information in Table 1, coupled with technical and operational data of the various technologies available in the literature, the selected criteria were weighted for each technology. These criteria were ranked from "very high" in situations where a criterion is considered to be of utmost importance in the adoption of the technology to "very low" where a criterion plays little or no role in the adoption of the technology. This gave rise to Table 3.

Data from Table 3 was analyzed using AHP and TOPSIS methods. To effect this, the table was first used with a 5-point Likert scale of the following values: Very low for 1, low for 3, moderate for 5, high for 7, and very high for 9. Using these absolute values relative ones were generated by comparing one technology with another relative to a criterion, then one criterion with another based on the intensity of their impact on the selection of the technologies. Saaty's Scale of Relative Importance was used to interpret the values obtained [19].

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Table 1: Summary of water treatment technologies considered in the study

Technology	Concise description
Microfiltration	A membrane technology operated at a low pressure of < 2 bars, with a pore size of 100-1000 nm; uses mechanical sieving to accomplish separation.
Ultrafiltration	A membrane technology operated at a low pressure of 2-10 bars, with a pore size of 5-50 nm; accomplishes separation by mechanical sieving which forces water through the membrane.
Nanofiltration	A membrane technology operated at a high pressure of 5-40 bars, with a pore size of 2-5 nm; employs physical rejection on the basis of molecular charge and size; uses capillary flow or solution diffusion to accomplish separation.
Reverse osmosis	A membrane technology operated at a high pressure of 10-100 bars, with a minute pore size of $<10^{-6}$nm; employs capillary flow to accomplish separation; achieves a higher rejection of all solids; "hyperfiltration".
Forward osmosis	A membrane process which employs the osmotic difference in pressure between the feed solution and an artificial draw solution, the structure of the membrane, the species of the dissolved solids, and the feed fouling capacity to induce water flux; "manipulated osmosis," "engineered osmosis" or "osmosis".
Ion exchange technology	A process used to exchange unwanted ionic substances in water with a non-objectionable one in a resin column; the unwanted ions are ejected with wastewater.
Electrodialysis	A membrane technology in which ions are moved through a membrane which selects ions, in a cell having an applied electric potential, to form a desalted diluate and a concentrated concentrate flows; practically, a stack comprises multiple cells.
Electrodialysis reversal	A membrane technology operated like electrodialysis save that the polarity of the applied electric current is reversed periodically, to reverse the direction of ion flow and prevent membrane fouling.
Electrodeionization	A membrane technology which applies no chemicals, and employs direct current power to massively reduce ions in water; in continuous electrodeionization, electric current continuously regenerates anion and cation exchange resins; each stack or module is made up of cell pairs containing cathodes and anodes on different sides.
Desalination	A technique, comprising membrane and thermal technologies, used for removing the undesirable salts in brackish water or seawater to convert it to usable water.

Table 2: Summary of criteria for water treatment technology selection

Aspects	Requirements	Sub-requirements	Indicator	QT/QL*	MX/MN**
Management	Technology	Local resources, materials use and reproducibility.	Percentage of technology materials and resources which cannot be obtained locally.	QT	MN
		Small-scale technology.	Project size (i.e. land and energy utilized)	QL	MN
Health	Impact		Reduction of children mortality due to diarrhoeal diseases.	QL	MX
Affordability	Economy		Low-cost availability and access, ability to pay	QT	MX
Environment	Impact	Atmospheric emissions, etc.	Greenhouse gases and other emissions (particulate matter, sulphur oxides), etc.	QT	MN
Legality	Regulations and standards		Legal implications incurred.	QL	MN
Power	Energy		Quantity of energy consumed	QT	MN
Capacity	Quantity		Volume of water treatable at once.	QT	MX

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Operation and maintenance	Ease/convenience		Ease of operation and maintenance.	QT	MX
Adaptability	Versatility		Scope for multiple uses and useful byproduct formation.	QT	MX
Quality	Efficiency		Reliability and effluent water quality.	QL	MX

*Quantity/quality (QT/QL): how is this criterion evaluated? **Maximum/minimum (MX/MN): which is more desirable for this criterion?

Table 3: Effect of criteria for selection on water treatment technologies

S/N	Criteria	MF	IX	EDR	RO	FO	DES	EDI	UF	ED	NF	Criterion weight
1	TR	M	H	H	H	H	H	VH	M	H	H	7
2	HI	L	L	H	H	M	L	H	M	H	H	7
3	ECO	H	M	M	L	H	M	H	H	M	M	9
4	EI	L	VH	M	M	M	VH	VL	L	M	L	7
5	QR	VH	H	H	VH	VH	VH	H	VH	H	VH	7
6	LA	M	H	M	M	M	VH	L	L	L	L	5
7	EOM	M	L	VH	L	H	L	H	M	M	L	7
8	ER	L	H	M	M	L	H	M	L	M	M	7
9	TV	L	H	VH	VH	VH	VH	M	M	VH	H	7
10	EFF	L	M	H	H	M	M	H	M	M	H	9

KEY

MF – Microfiltration	TR – Technology requirement	ECO – Economy	FO – Forward osmosis
HI – Health impact	EI – Environmental impact	IX – Ion exchange technology	RO – Reverse osmosis
ED – Electrodialysis	TV – Treatment versatility	QR – Quantity requirement	DES – Desalination
NF – Nanofiltration	EFF – Efficiency	LA – Legal aspects	EDI – Electrodeionization
VH – Very high	H – High	ER – Energy requirements	UF – Ultrafiltration
M – Moderate	L – Low	EDR – Electrodialysis reversal	
VL – Very low	EOM – Ease of operation and maintenance		

Procedure for AHP

The fundamental procedure for carrying out AHP comprises a number of steps [20]. First, structuring the decision problem and choosing the criteria: at this step, the decision problem was decomposed into its component parts. This structure comprised a goal at the apex, the criteria and sub-criteria at the middle, and the alternatives at the base, as shown in Figure 1.

At the second step, a priority setting of the alternatives and the criteria was effected by pairwise comparison: a weight between 1 and 9 was assigned to the more important of a pair of alternatives under comparison, whereas its inverse was assigned to the second alternative. At the third step, an overall relative score was obtained for each alternative: by simple weighted summation, the alternative scores were combined with the criterion weights to give an overall score for each alternative. At the fourth step, pairwise comparison matrices were then formulated: the values obtained from the pairwise comparisons were used to form the upper diagonals of the pairwise comparison matrices while their inverses were used to fill in the corresponding slots in the lower diagonals. At the fifth step, eleven 10 x 10 matrices, one for each criterion and one criteria matrix, were formed using the results of the pairwise comparison of alternatives.

At the sixth step, the resulting matrices were normalized, by calculating the geometric mean of the elements in each row, to get a column matrix, and dividing each element in this matrix by the sum of the column elements. This gave rise to the principal eigenvectors of the pairwise comparison matrices of alternatives relative to the criteria, which, by interpretation, were the weights of the different alternatives relative to each criterion. Similarly, the principal eigenvectors of the normalized criteria matrix gave the relative weights of the criteria (W_j).

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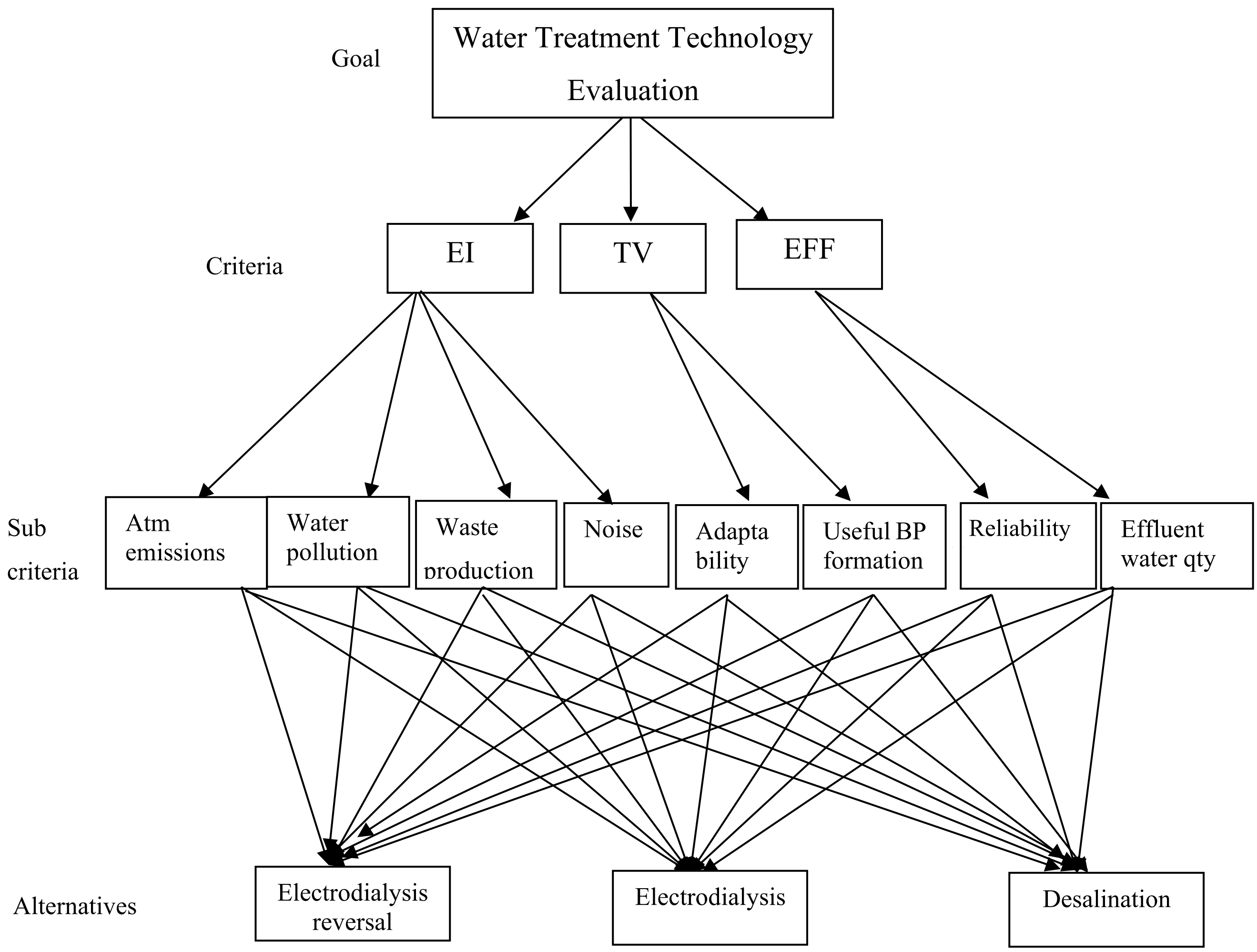

Figure 1: The hierarchical structure of AHP

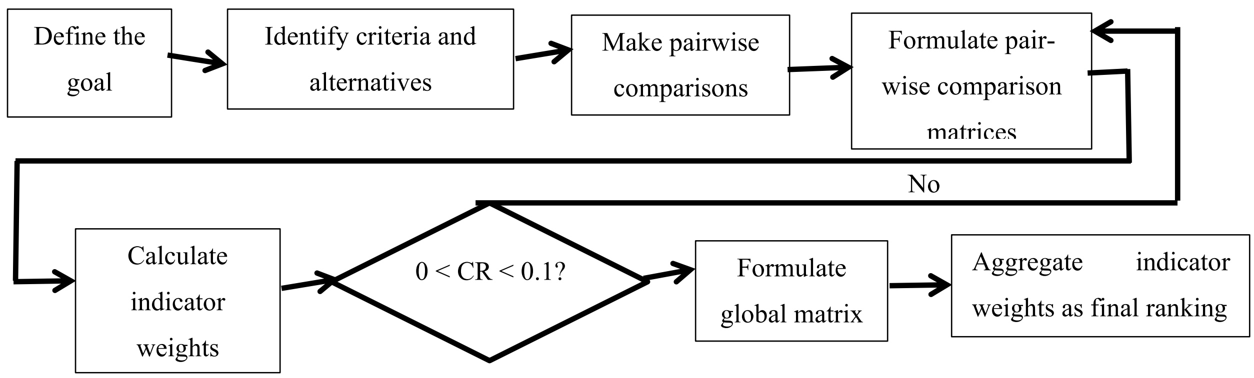

Figure 2: Flowchart of AHP steps

From the results obtained, a decision matrix was formed using the normalized principal eigenvectors of the alternatives relative to each criterion for each column and the weights of the different criteria above each column. This was used to obtain the final ranking of the alternatives. Using the decision matrix, the final ranking was obtained as given below:

$$\sum_{j=1}^{m} B_{ij} W_i = \text{final ranking} \quad (1)$$

Where j = 1 to m; B_{11} to B_{1010} are the eigenvectors corresponding to the weight of the alternatives relative to each criterion; W_1 to W_{10} are the eigenvectors corresponding to the weights of the criteria. These steps are illustrated in Figure 2.

TOPSIS application

To apply this method, the criteria were grouped according to cost attributes ("less is more desirable"): technology requirement, energy requirements, environmental impact and legal aspects, and benefit attributes ("more is more desirable"): health impact, ease of operation and maintenance, quantity requirement, treatment versatility, economy and efficiency. This method makes use of the decision matrix obtained using AHP as its starting matrix [21]. This starting matrix was normalized as follows: $R = (r_{ij})_{m \times n}$, where $r_{ij} = B_{ij} / (\sum B_{ij}^2)^{1/2}$ for $i = 1, \ldots .m$; $j = 1, \ldots, n$. A weighted normalized matrix was formed to give $v_{ij} = W_j \, r_{ij}$. W_j corresponded to the weight of the criteria while r_{ij} corresponded to each element in the normalized matrix. The positive ideal and negative ideal solutions, PIS and NIS, were obtained, respectively, by

PIS $= \{vi^*, \ldots, v_n *\}$, where

$$v_j = \{\min(v_{ij}) if\ j \in J; \max(v_{ij}) if\ j \in J'\} \quad (2)$$

NIS $= \{v_1', \ldots, v_n'\}$, where

$$v_j' = \{\max(v_{ij})\ if\ j \in J; \min(v_{ij})\ if\ j \in J'\} \quad (3)$$

The PIS was obtained by taking the maximum value of the options relative to the benefit attributes and the minimum value of the options relative to the cost attributes. The reverse was the case for the NIS.
Then, the measure of separation from the PIS by Euclidean distance was obtained from Equation 4.

$$S_i * = \left[\sum(v_i * - v_{ij})^2\right]^{1/2} \quad (4)$$

where v_j* was the PIS of the alternatives relative to criterion j, and v_{ij} was the weighted normalized vector corresponding to the alternatives relative to the same criterion. The separation from the NIS was given by

$$S'_j = \left[\sum(v_i' - v_{ij})^2\right]^{1/2} \quad (5)$$

where v'_j was the NIS of the alternatives relative to criterion j, and v_{ij} was the weighted normalized vector corresponding to the alternatives with respect to the same criterion. The relative closeness to the ideal solution C_i* was calculated as follows.

$$C_i^* = \frac{S'_i}{(S_i^* + S'_i)}, 0 < C_i^* < 1 \quad (6)$$

where S_i* was the separation from the PIS of alternative i, and S'_i was the separation from the NIS of the same alternative. The option with the highest relative closeness to 1 was the best. The PIS and NIS are highlighted in Tables 4 and 5. Table 6 gives the decision matrix and final ranking by AHP method.

Check for Consistency

The consistency ratio (CR) was calculated for each of the pairwise comparison matrices, to measure the consistency of the judgments relative to big samples of totally random judgments. According to Thomas Saaty, if CR exceeds 0.1, the judgments are unreliable being too close to randomness, and the work was futile and must be redone [22]. The consistency ratios were all found to be satisfactory.

Modification of TOPSIS method

A cursory look at the separation measure from the PIS and NIS reveals a variation in the distance between the two for each alternative. But the separation between the two ideal solutions is supposed to be equal for all the alternatives for there to be equal basis for obtaining the proximity to the ideal solution. Hence, to address this deviation, the separation measures from the positive and negative ideal solutions were normalized in the following way:

$$S_i^{**} = \frac{\text{Max}\,(S_i^* + S_i') - (S_i^* + S_i')}{2} + S_i^* \quad (7)$$

$$S_i'' = \frac{\text{Max}\,(S_i^* + S_i') - (S_i^* + S_i')}{2} + S_i' \quad (8)$$

S_i^{**} and S_i'' were the normalized separation from the PIS and NIS respectively. In practical terms, it is equivalent to moving the NIS to the left and PIS to the right by equal measures. This operation takes the positions of the ideal solutions to those of the alternative with the longest separation between ideal solutions, i.e. Max (S_i^* +S_i'').
Hence the closeness to the ideal solution had to be recalculated as follows:

$$C_i^* = S_i'' / (S_i^{**} + S_i''), 0 < C_i^* < 1 \quad (9)$$

This is an iterative approach. These steps are illustrated in Figure 3.

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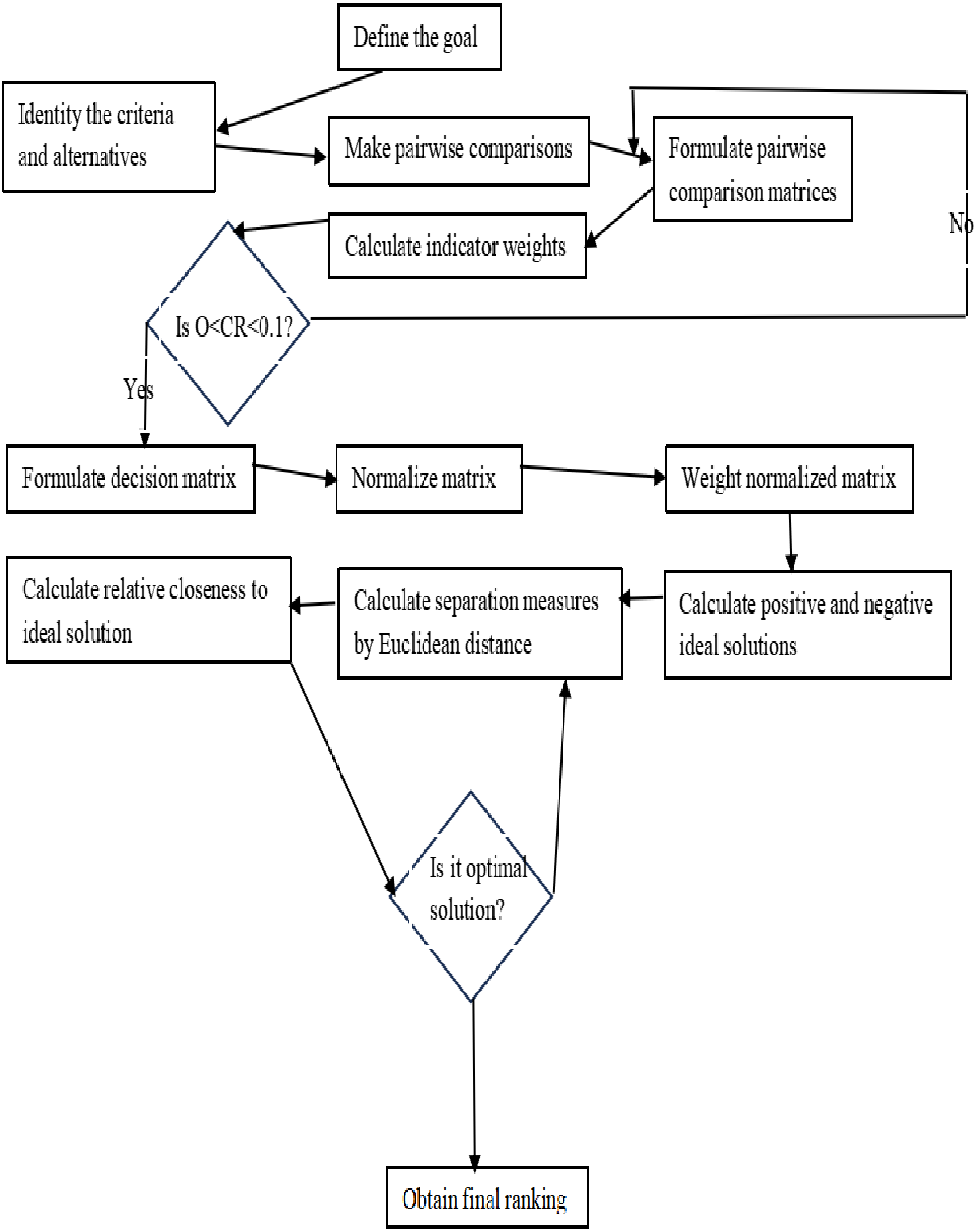

Figure 3 Flowchart of TOPSIS steps

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Table 4: The positive ideal solution

	ECO	HI	TR	EI	QR	LA	EOM	ER	TV	EFF
MF	0.012	0.016	0.049	0.037	0.014	0.062	0.014	0.044	0.033	**0.032**
IX	0.022	0.016	0.026	**0.009**	0.025	0.062	0.026	0.015	**0.057**	0.011
EDR	0.042	**0.047**	0.014	0.037	0.058	0.062	**0.049**	**0.009**	0.017	0.011
RO	0.022	0.028	0.026	0.037	0.014	0.062	0.026	0.026	0.017	0.006
FO	**0.042**	0.047	0.026	0.013	0.014	0.062	0.049	0.044	0.017	0.011
DES	0.022	**0.010**	0.026	0.009	0.014	**0.021**	0.026	0.015	0.017	0.011
EDI	0.042	0.010	**0.014**	0.021	0.014	0.062	0.026	0.015	0.033	0.006
UF	0.012	0.016	0.049	0.037	0.014	0.062	0.014	0.044	0.033	0.020
ED	0.042	0.047	0.026	0.037	**0.058**	0.062	0.026	0.015	0.017	0.020
NF	0.022	0.028	0.026	0.037	0.025	0.062	0.026	0.044	0.033	0.011

Bold values indicate the positive ideal values which correspond to the maximum and minimum column entry for the benefit and cost attributes respectively.

Table 5: The negative ideal solution

	ECO	HI	TR	EI	QR	LA	EOM	ER	TV	EFF
MF	**0.012**	0.016	**0.049**	**0.037**	**0.014**	**0.062**	**0.014**	**0.044**	0.033	0.032
IX	0.022	0.016	0.026	0.009	0.025	0.062	0.026	0.015	0.057	0.011
EDR	0.042	0.047	0.014	0.037	0.058	0.062	0.049	0.009	**0.017**	0.011
RO	0.022	0.028	0.026	0.037	0.014	0.062	0.026	0.026	0.017	0.006
FO	0.042	0.047	0.026	0.013	0.014	0.062	0.049	0.044	0.017	0.011
DES	0.022	**0.010**	0.026	0.009	0.014	0.021	0.026	0.015	0.017	0.011
EDI	0.042	0.010	0.014	0.021	0.014	0.062	0.026	0.015	0.033	**0.006**
UF	0.012	0.016	0.049	0.037	0.014	0.062	0.014	0.044	0.033	0.020
ED	0.042	0.047	0.026	0.037	0.058	0.062	0.026	0.015	0.017	0.020
NF	0.022	0.028	0.026	0.037	0.025	0.062	0.026	0.044	0.033	0.011

Bold values indicate the negative ideal values which correspond to the minimum and maximum column entry for the benefit and cost attributes respectively.

Table 6: Decision matrix and final ranking by AHP method

Global matrix	ECO	HI	TR	EI	QR	LA	EOM	ER	TV	EFF	Rank	Position
Weight	0.1702	0.0876	0.0876	0.0876	0.0876	0.0464	0.0876	0.0876	0.0876	0.1702		
MF	0.0443	0.0608	0.1743	0.1357	0.0545	0.1071	0.0489	0.1629	0.1204	0.2300	0.1079	5th
IX	0.0789	0.0608	0.0923	0.0313	0.1004	0.1071	0.0923	0.0550	0.2086	0.0785	0.0926	7th
EDR	0.1490	0.1781	0.0489	0.1357	0.2362	0.1071	0.1743	0.0333	0.0620	0.0785	0.1210	2nd
RO	0.0789	0.1053	0.0923	0.1357	0.0545	0.1071	0.0923	0.0952	0.0620	0.0464	0.0907	8th
FO	0.1490	0.1781	0.0923	0.0477	0.0545	0.1071	0.1743	0.1629	0.0620	0.0785	0.1118	3rd
DES	0.0789	0.0364	0.0923	0.0313	0.0545	0.0357	0.0923	0.0550	0.0620	0.0785	0.0586	10th
EDI	0.1490	0.0364	0.0489	0.0757	0.0545	0.1071	0.0923	0.0550	0.1204	0.0433	0.0825	9th
UF	0.0443	0.0608	0.1743	0.1357	0.0545	0.1071	0.0489	0.1629	0.1204	0.1440	0.1036	6th
ED	0.1490	0.1781	0.0923	0.1357	0.2362	0.1071	0.0923	0.0550	0.0620	0.1440	0.1226	1st
NF	0.0789	0.1053	0.0923	0.1357	0.1004	0.1071	0.0923	0.1629	0.1204	0.0785	0.1087	4th

3.0 RESULTS AND DISCUSSION

The results obtained show that the most important criteria affecting the selection of the water treatment technologies are economy and efficiency. These two account for about 34% of the ranking. Legal aspects is the least important, accounting for less than 5% of the ranking. The rest were found to weigh equally in importance, accounting collectively for about 61% of the ranking.

These results are illustrated in Figure 4.

For the alternatives, electrodialysis was ranked the best by AHP with a rank of 12.26%, followed by

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electrodialysis reversal (12.10%), forward osmosis (11.18%), nanofiltration (10.87%), microfiltration (10.70%), ultrafiltration (10.36%), reverse osmosis (9.07%), electrodeionization (8.25%), ion exchange technology (7.26%), and desalination (5.86%).

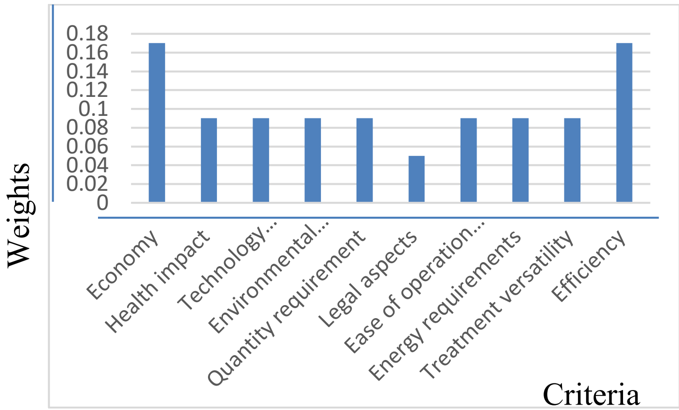

Figure 4: Weights of criteria obtained from pairwise comparison

On the other hand, according to TOPSIS, ion exchange technology ranked best with 12.84%, followed by electrodialysis reversal (12.62%), desalination (12.56%), electrodeionization (11.94%), electrodialysis (11.30%), forward osmosis (9.40%), nanofiltration (7.79%), microfiltration (7.53%), reverse osmosis (7.25%), and ultrafiltration (6.76%). These results are shown in Table 7.

Effect of criteria on selection of water treatment technology

This analysis shows that efficiency and economy are the most important criteria. This is understandable as affordability and quality receive prime consideration in most engineering systems [23]. Except for legal aspects, the other criteria ranked equally at 8.76%. More often than not, if there is no incorruptible supervision in place, water quality standards and regulations are hardly observed meticulously [24].

Ranking of water treatment technologies by AHP and TOPSIS

The results obtained were consistent, indicating that the data used were not random and can be relied upon for water treatment technology selection [25]. AHP as the name implies gave the hierarchies of the different alternatives, i.e. the ranking, while TOPSIS showed the closeness of the alternatives to the idea solution, i.e. a rank value of 1.

With AHP, the best ranked water treatment technologies are electrodialysis, electrodialysis reversal, and forward osmosis. These are all advanced and highly efficient technologies which are used for large quantity water treatment mainly in the developed countries of the world, where which water treatment technology to employ depends more on effluent water quality than on influent water quantity [26].

Coming after these are nanofiltration, microfiltration and ultrafiltration. These are all membrane filtration processes which may not achieve high purification like the best ranked water treatment technologies (but for nanofiltration), but are more affordable, treat more volumes of water per time, and does not require high technological expertise for operation like the least ranked ones [27].

The least ranked are ion exchange technology, reverse osmosis, electrodeionization and desalination. These technologies may not achieve as much water purification economically as the higher ranked ones and yet may not treat as much volumes of water per time as the next best ranked (but for desalination) [28]. However, what desalination gains in quantity of water treatable, it loses even more in the quality of the effluent water [29].

With TOPSIS, the best ranked technologies are ion exchange technology, electrodialysis reversal and desalination. Now, this method is all about proximity to the ideal solution or distance from the non-ideal solution, or both. This means that alternatives with low cost attributes or high benefit attributes or both naturally score high here. All the best ranked water treatment technologies here score low in at least one of the cost attributes and high in at least two of the benefit attributes [30].

The next ranked technologies are electrodeionization, electrodialysis, and forward osmosis. These are not as far from the non-ideal solution and as close to the ideal solution as the best ranked water treatment technologies [31]. The least ranked here are nanofiltration, microfiltration, reverse osmosis, and ultrafiltration. These are closest to the non-ideal solution and furthest from the ideal solution than the others [32].

Effect of modification of TOPSIS method on ranks

The result of the modification done on the TOPSIS ranks to bring about normalization of the separations from the ideal solution is shown in Table 8.

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Table 7: Water treatment technologies by rank percentage

Alternative		MF	IX	EDR	RO	FO	DES	EDI	UF	ED	NF
Rank (%)	AHP	10.70	7.26	12.10	9.07	11.18	5.86	8.25	10.36	12.26	10.87
		5th	9th	2nd	7th	3rd	10th	8th	6th	1st	4th
	TOPSIS	7.53	12.84	12.62	7.25	9.40	12.56	11.94	6.76	11.30	7.79
		8th	1st	2nd	9th	6th	3rd	4th	10th	5th	7th

Table 8: Summary of ranking by TOPSIS

TOPSIS	IX	EDR	DES	EDI	ED	FO	NF	MF	RO	UF
	0.5203	0.5114	0.5089	0.4839	0.4579	0.3810	0.3157	0.3051	0.2936	0.2740
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Modified	0.5117	0.5114	0.5082	0.4855	0.4608	0.3881	0.3552	0.3255	0.3306	0.3053
TOPSIS	1st	2nd	3rd	4th	5th	6th	7th	9th	8th	10th

The ranks above 0.5 were either unchanged or slightly reduced while those below 0.5 slightly increased. Only microfiltration and reverse osmosis changed positions.
Figure 5 shows a pictorial depiction of the TOPSIS results. One strength of TOPSIS is its capacity to portray the proximity of alternatives to the ideal solution [33]. This is evident from the figure: ion exchange is closest to 1 while ultrafiltration is furthest from it.

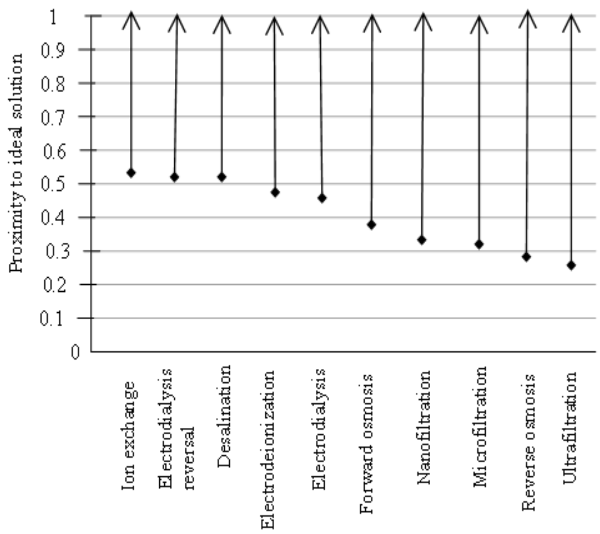

Figure 5: Ranking (plots of proximity to the ideal solution) for TOPSIS

4.0 CONCLUSION

As can be seen from the results obtained, the two most important of the ten reviewed criteria for selecting water treatment technologies are economy and efficiency while the least important is legal aspects. The other seven are equally important. Also, the two best-ranked water treatment technologies

obtained using AHP and TOPSIS are electrodialysis and ion exchange technology respectively. The first of these scored fifth with TOPSIS while the second scored ninth with AHP. The second best for both AHP and TOPSIS is electrodialysis reversal.
Therefore, with the high rank of electrodialysis reversal in both cases (2nd, 2nd), this study concludes it is the most effective among the water treatment technologies reviewed. This is so as this technology is highly efficient, makes high health impact and little environmental impact and is very versatile and self-sustaining [34].

This study has established that electrodialysis reversal is a superior water treatment technology to others reviewed for treating water at any scale. This means it can be seen as a good alternative to the conventional unit operations for municipal water treatment. Further studies can be carried out to certify this. The study also reveals the need for more efforts to create awareness of the necessity to observe water quality standards and regulations.

The study examined and compared ten different water treatment technologies against ten criteria using the 10 x 10 matrices generated. Previous studies on this concept limited the matrices to 7 x 7 at the most. The higher rank was bulkier but more comprehensive. Also, previous studies identified desalination as a process to be used in mainly the arid regions of the world with limited water supply. This study established it to be an effective water treatment process even in places with good water supply.

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In this study, a completely novel table was derived of the effect of criteria for selection on water treatment technologies. This can come in handy for choosing at glance which technology to apply for water treatment when some given criteria are a priority concern.

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