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A Fuzzy TOPSIS model Framework for Ranking Sustainable Water Supply Alternatives

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Abstract Recently water supply alternative sources, recognized as sustainable and ecofriendly have become popular. This is consequent on the scarcity and increasing demand for water, especially by developing nations characterized by industrialization and increasing population growth. However, the intricacies and overwhelming nature of factors to be considered in reaching a decision on a best alternative has further prompted the emergence of several decision support tools, some of which arouse discrepancies with setbacks. We employ here, the uniqueness of fuzzy TOPSIS (technique for order preference by similarity to ideal solution), a multi-criteria decision approach (MCDA), to aid in deciding the most preferred alternative water supply among, desalination, water borehole, rain water harvesting, reclaimed water, black water, grey water and water importation. This method is reckoned for its ease in handling both quantitative and qualitative data. Moreover it also overcomes the uncertainties in expert opinions usually encountered in the decision process due to the numerous variables, criteria and attributes that interplay in achieving sustainability. Results from analysis on data aggregation, normalization and performance ratings, coupled with the weighted distance from the positive and negative ideal solutions indicated that borehole ranked topmost followed by rain water harvesting (RWH). These revelations are apt to all stakeholders in the water delivery sector and in deliberations on the paradigm shift to water conservation and management measure.

Keywords MCDA · Alternative water supply · Fuzzy TOPSIS · Nigeria · Sustainability

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1 Introduction

Water is recognized as a commodity fundamental to health but scarce, and achieving adequate water delivery to the public can be an overwhelming task anywhere in the world, especially when characterized by increasing population, urbanization and industrialization, as in developing countries especially. Yoe 2002, described associated problems with urban water supplies in achieving sustainability as a wicked task, since no answer can exactly be termed right, hence a compromise situation or solution is usually opted for. This is because the problem of uncertainty and human rationality is encapsulated in all wicked problems (Khisty and Mohammadi 2001).

The renaissance to non-conventional or alternative water supply options are recognized as ecofriendly and sustainable, and their integration globally such as, reclaimed water, grey water, black water, rain water harvesting (RWH), desalination, borehole water, water importation, into water supply schemes is intrinsic. Hence exploring these pathways usually borders on the ‘soft path’ approach which suggest a combination of supply options that is usually not technology driven and viable, especially in new urban areas where no central infrastructure pre-exist. These systems undoubtedly can limit demand for fresh water resources, diversify water source, boost reliability of access to resource, and minimize volume of waste water discharged into the environment. These supply options over time, have undergone and undertaken diverse research patterns (Ukpong and Agunwamba 2012; Mara 2004; Dolnicar 2009; Contard and Gouvello 2013; Chowdhury and Rahman 2008; Kanakoudis et al. 2011; Angelakis and Gikas 2014).

However the numerous difficulty, rigor, variability of criteria, and uncertainty encountered/ interplay during the decision making process for the best or appropriate supply option endears our employ of multi-criteria decision making approach (MCDA), a decision support tool in overcoming these shortcomings. Fuzzy TOPSIS (technique for order preference by similarity to ideal solution), is a MCDA approach, employed in this study for the first time in alternative water supply option, with consideration of the socio-cultural input in its analysis, a fundamental aspect of sustainability, to evaluate the preferred water supply alternative in the eastern Niger delta of Nigeria, based on economic, technical, environmental and socio-cultural criteria. This region is endowed with water resources including over 2200 mm of annual rainfall, but yet faced with gross inadequacies in water supply, evidenced by the proliferation of water vendors, a clear indication that supply are below acceptable levels. This condition is prevalent in most other parts of the country (Sule et al. 2010). (Okoli et al. 2010) identified major alternative sources of water in the region to be boreholes, wells and ground water.

2 Literature Review

MCDA approaches are recognized to operate on two basic dimensions namely, providing insight into the nature of conflicts amongst objectives and arriving at a consensus around stakeholders rather than eliminating conflicts (Kheireldin and Fahmy 2001). Amongst them, fuzzy TOPSIS, an upgrade from traditional TOPSIS, pioneered by Hwang and Yoon (1981), is unique because it’s easy to understand and effectively handles both qualitative and quantitative data in multi attribute decision making (MADM). This approach utilizes linguistic variables in its evaluation process thus resolving the major deficiency of using crisps data in traditional TOPSIS, which is usually inadequate in reality modelling. It is conceptualized on the basis that the chosen alternative should have the shortest distance from the positive ideal solution and the farthest distance from negative ideal solution. Positive ideal solution optimizes the benefit criteria and minimizes cost criteria, while the negative ideal solution reverses the case i.e. maximizes the cost criteria and minimizes the benefit criteria Wang and Elhag 2006.

Fuzzy TOPSIS in research, has been widely documented (Chen 2000; Chu and Lin 2003; Bottani and Rizzi 2006; Abrishamchi et al. 2005; Afshar et al. 2011). Contemporary studies on non-conventional water resources supply synonymous to MCDA methods include (Marcia and Buros 1985; Abulnour et al. 1983; Song et al. 2011; Yoshiaku and Toshiya 2011). Distinctly, Marwan and Numan 2004 in the Middle East, recommended an integration of both conventional and non-conventional options for better viability, laying emphasis on non-conventional option for overcoming water shortages. Jaber and Mohsen 2001 in Jordan, utilized analytical hierarchy process (AHP), under economic, technical, reliability, availability and environmental criteria. Desalination, followed by rain water harvesting was documented to be the most promising option. In the same vein, Okeola and Sule 2012 in Kwara state Nigeria evaluated management alternatives using AHP for urban water supply system. They resolved that public ownership and operation were the people's choice in contributing more to sustainable operation of urban water supply service delivery under scrutiny of environmental, economic, technical, institutional and socio-cultural criteria. Tahereb et al. 2015 in Iran evaluated urban water supply system employing a distance based fuzzy MCDA approach, their studies revealed that of the four alternatives of PET bottled drinking water, private desalinated water suppliers, household desalinated water units and public desalinated water, public desalinated was the most appropriate to supply drinking water in the region. From what we know so far, there are hardly explicit reports employing our approach in this area.

3 Method

The information used for this study was gathered from archival records and interviews with experts in water supply sector in Nigeria. The area under focus has a population of approximately five million people with about 3.2% growth rate. First, a deduction process (see online resource Tables 1 and 2) is employed to ascertain the relevant sustainability factors to select the best sustainable water supply alternative. The information on the deduction process was sourced via questionnaires from 50 managers and researchers in the field of water supply (respondents were from both private and government levels, with at least 10 years professional experience and minimum of graduate level education) and the elite responses were checked for

Table 1 Sustainability factors/criteria for water supply option selection

Criteria	Sub- criteria
Economic	
	Cost
	Quality
Environmental	
	Green design
	Environmental competencies
	Pollution control
	Reliability
Technical (Infrastructure)	
	Operational efficiency
Social	
	Public health and safety
	Respect for the policy
	Coverage

Table 2 Fuzzy linguistic scale

Linguistic term	Score	Triangular fuzzy numbers
Very weak	1	(0, 0, 0.25)
Weak	2	(0, 0.25, 0.50)
Medium	3	(0.25, 0.50, 0.75)
Good	4	(0.50, 0.75, 1.00)
Very good	5	(0.75, 1.00, 1.00)

consistency. The responses to the deduction process for sorting the sustainability factors relevant for alternative supply options are converted to percentages. A threshold is set at 85% for the responses to the deduction process. Thus, the sustainability factors crucial for selection of best water supply options are reflected in Table 1.

The sustainability factors stated in Table 1 is employed in this work to obtain the best sustainable water supply alternative.

3.1 Model Formulation

This study proposes a multi- criteria decision making model to select the best alternative supply. While developing the proposed model based on fuzzy- TOPSIS, the sustainability factors/sub- criteria relevant to water supply options, linguistic scale and water supply alternatives were progressively defined.

3.1.1 Sustainability Factors

The sustainability factors are economic, environmental, technical and social, while the relevant sub-criteria are, economic sub- criteria include cost and quality; environmental sub- criteria include environmental competencies (EC), pollution control, reliability and green design (GD); technical sub- criteria include operational efficiency while social sub- criteria include respect for policy (RFP), coverage and public health and safety.

3.1.2 Linguistic Scale

This is a qualitative scale utilized to collect evaluator's judgment. The fuzzy linguistic scale employed has linguistic terms of very weak, weak, medium, good and very good with scores of 1, 2, 3, 4 and 5 and triangular fuzzy numbers of (0,0,0.25), (0,0.25,0.50), (0.25, 0.50, 0.75), (0.50, 0.75, 1.00) and (0.75,1.00, 1.00) respectively.

3.1.3 Alternatives

In this model, an alternative was defined as any available sustainable water supply option.

Fuzzy- Based Calculations The fuzzy linguistic scale for the study is shown in Table 2 below.

To obtain the information on the performance of water supply options with respect to the deduced sustainability sub- criteria, fuzzy design questionnaires were administered to 20 water supply experts and the fuzzy linguistic scale in Table 2 above was applied to obtain the decision matrix with elements A_i, S_i and P_{ij}, shown in Table 3.

Table 3 Performance of water supply alternatives with respect to sustainability sub-criteria

Alternatives	Sub- criteria			
	S_1	S_2	S_3	S_n
A_1	P_{11}	P_{12}	P_{13}	P_{1n}
A_2	P_{21}	P_{22}	P_{23}	P_{2n}
A_m	P_{m1}	P_{m2}	P_{m3}	P_{mn}

(A_i, S_i and P_{ij} are sustainability sub- criteria, water supply alternatives and deducted water supply performance with regards to the sustainability factor respectively).

The data on Table 3 will serve as input data to the multi- criteria decision making model that will be developed (Fig. 1).

A diffuzification process known as Converting Fuzzy data into Crisps Scores (CFCS) process is utilized to diffuzify the fuzzy set into crisp values. Researchers, emphasize its

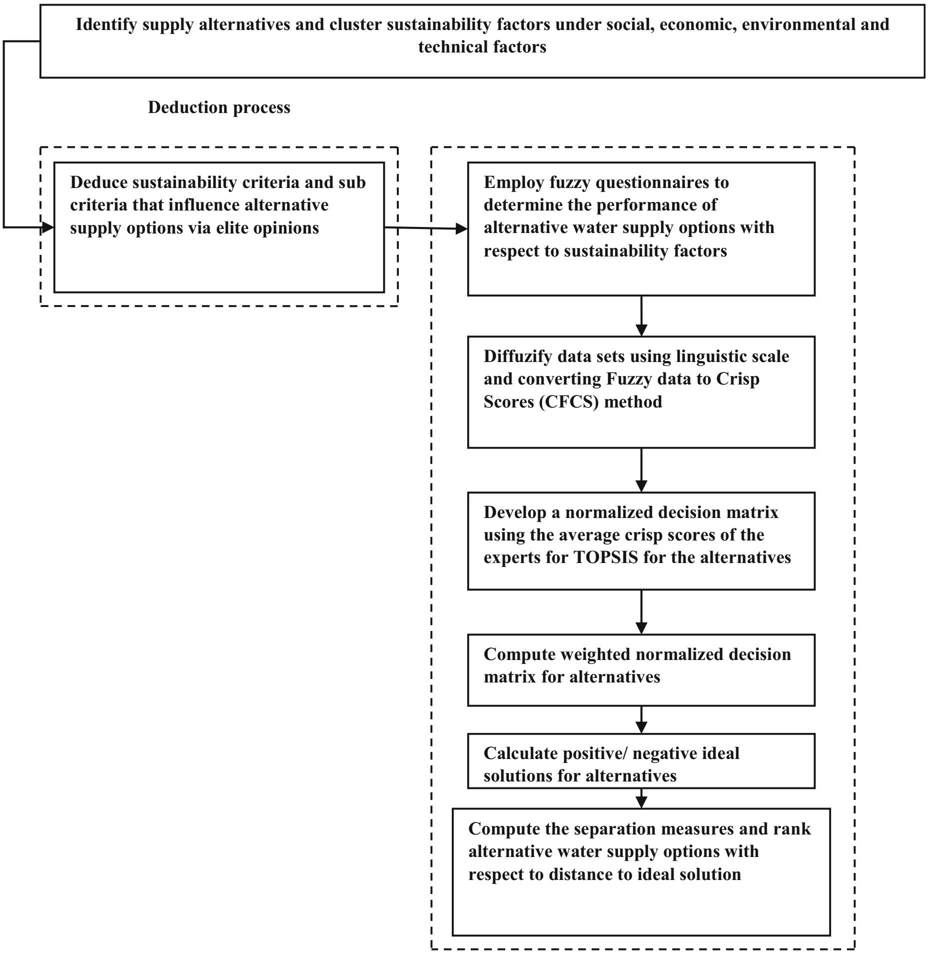

Fig. 1 Fuzzy TOPSIS model based approach for ranking alternatives

effectiveness in arriving at crisp values when compared to the centroid method (Gharakhani 2012). A triangular fuzzy number can be shown as $q = (r, s, t)$ and the triangular membership function $\tilde{u}r_q$ is defined as Eq. (1).

$$\tilde{u}'_q(s) = \begin{cases} 0 & if\ s < a \\ \frac{(s-a)}{(b-a)} & if\ a \leq s \leq b \\ \frac{(c-s)}{(c-b)} & if\ b \leq s \leq c \\ 0 & if\ s > c \end{cases} \tag{1}$$

CFCS typically determines fuzzy maximum and minimum of the fuzzy number range. According to the membership function $\tilde{u}r_q$, the total score is calculated with the weighted average. Given that U represents a fuzzy set, the fuzzy evaluation is given by $\tilde{u}r_{ij}^{d} = (r^{d}_{ij}, s^{d}_{ij}, t^{d}_{ij})$ for decision makers $d = (1, 2 \ldots n)$ for the degree of influence of sub- criterion i on sub-criterion j. The CFCS method involves a five- step algorithm described as follows:

Step One: Normalization:

$$ra^{n}{}_{ij} = \left(a^{n}{}_{ij} - \text{minc}^{n}{}_{ij}\right)/\Delta^{max}{}_{min} \tag{2}$$

$$rb^{n}{}_{ij} = \left(b^{n}{}_{ij} - \text{minc}^{n}{}_{ij}\right)/\Delta^{max}{}_{min} \tag{3}$$

$$rc^{n}{}_{ij} = \left(c^{n}{}_{ij} - \text{minc}^{n}{}_{ij}\right)/\Delta^{max}{}_{min} \tag{4}$$

$$Where \Delta^{max}{}_{min} = \text{maxa}^{n}{}_{ij} - \text{minc}^{n}{}_{ij} \tag{5}$$

Step Two: Compute right (bo) and left (ko) normalized values:

$$rbo^{n}{}_{ij} = ra^{n}{}_{ij}/\left(1 + ra^{n}{}_{ij} - rb^{n}{}_{ij}\right) \tag{6}$$

$$rko^{n}{}_{ij} = rb^{n}{}_{ij}/\left(1 + rb^{n}{}_{ij} - rc^{n}{}_{ij}\right) \tag{7}$$

Step Three: Compute total normalized crisp values:

$$r^{n}{}_{ij} = \left[rko^{n}{}_{ij}\left(1 - rko^{n}{}_{ij}\right) + rbo^{n}{}_{ij}\ X\ rbo^{n}{}_{ij}\right]/\left[1 - rko^{n}{}_{ij} + rbo^{n}{}_{ij}\right] \tag{8}$$

Step Four: Compute crisp values:

$$u^{n}{}_{ij} = \text{minc}^{n}{}_{ij} + r^{n}{}_{ij}\, X \Delta^{max}{}_{min} \tag{9}$$

Step Five: Integrate crisp values:

$$u_{ij} = 1/p\left(u^{1}{}_{ij} + u^{2}{}_{ij} + \ldots + u^{p}{}_{ij}\right) \tag{10}$$

TOPSIS-Based Calculations TOPSIS is presented to rank the sustainable water supply alternatives. The steps in TOPSIS- based calculations involves developing normalized decision matrix, computing weighted normalized decision matrix for the alternatives, calculating the ideal negative and positive solutions for the different alternatives, computing separation measures for the respective alternatives and calculating the relative closeness of the alternatives to ideal solution.

Step one: Developing normalized decision matrix

Table 4 is developed with element F_{ij} which represents the normalized evaluation index for the alternative sustainable water supply options.

F_{ij} is computed as:

$$F_{ij} = \frac{h_{ij}}{\sqrt{\sum_{i=1}^{m} h^{2}{}_{ij}}} \tag{11}$$

Where,

h_{ij} is the performance of each water supply alternative with respect to each sustainability criterion.

Step two: Computing weighted normalized decision matrix

The weighted normalized decision matrix L_{ij} is calculated as:

$$L_{ij} = F_{ij} \text{ x } \alpha_{ij} \tag{12}$$

Table 4 Normalized decision matrix

Alternatives	Sub- criteria			
	S_1	S_2	S_3	S_n
A_1	P_{11}	P_{12}	P_{13}	P_{1n}
A_2	P_{21}	P_{22}	P_{23}	P_{2n}
A_m	P_{m1}	P_{m2}	P_{m3}	P_{mn}

Step three: Calculation of ideal positive and negative solutions for the alternatives

The ideal (L_j^+) and negative ideal (L_j^-) solutions are determined as:

$$L_j^+ = \{l_i^+ \ldots l_n^+\} = \left[\left(max\, l_{ij} \,\middle|\, i \in A^{'}\right), \left(min\, l_{ij} \,\middle|\, i \in A^{\wedge}\right)\right] \tag{13}$$

$$L_j^- = \{l_i^- \ldots l_n^-\} = \left[\left(min\, l_{ij} \,\middle|\, i \in A^{'}\right), \left(max\, l_{ij} \,\middle|\, i \in A^{\wedge}\right)\right] \tag{14}$$

Where *A’* is associated with advantage criteria, and *A*” is associated with cost criteria.

Step four: Computing the separation measures

The separation measures (k_i^+ and k_i^-) are computed using the n- dimensional Euclidean distance for the alternatives as:

$$k_i^+ = \sqrt{\sum_{j=1}^{n} \left(l_{ij} - l_j\right)^2} \tag{15}$$

Where,
$i = 1, 2\ldots m$; l_j (in Eq. 12) = l_j^+

$$k_i^- = \sqrt{\sum_{j=1}^{n} \left(l_{ij} - l_j\right)^2} \tag{16}$$

Where,
$i = 1, 2 \ldots m$; l_j (in Eq. 13) = l_j^-

Step five: Calculation of relative closeness to ideal solution

The relative closeness of the alternatives (a_j) to the ideal (Y^*) solution is computed as:

$$E_i = \frac{k_i^-}{k_i^- + k_i^+} \qquad 0 \le E_i \le 1 \tag{17}$$

Where *A’* is associated with advantage criteria, and.
A” is associated with cost criteria.
Finally, the alternative water supply options are ranked with respect to their relative closeness to the ideal solution in order of preference.

4 Results and Discussions

Microsoft EXCEL and MATLAB were employed for data analysis. The relevant sustainability factors are classified into technical (infrastructure), social, economic and environmental criteria. The economic sub- criteria include cost and quality; environmental sub- criteria

Table 5 Triangular fuzzy numbers of an expert

	A_1	A_2	A_3	A_4	A_5	A_6	A_7
PHS	(0, 0, 0.25)	(0, 0.25, 0.50)	(0, 0, 0.25)	(0.75, 1, 1)	(0,0.25, 0.5)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
Rel	(0.75,1, 1)	(0.25,0.5,0.75)	(0.75,1, 1)	(0,0.25,0.5)	(0,0.25,0.5)	(0, 0, 0.25)	(0.25,0.5,0.75)
Cost	(0, 0, 0.25)	(0.25,0.5,0.75)	(0,0.25, 0.5)	(0.50,0.75,1)	(0.75,1,1.)	(0,0.25, 0.5)	(0, 0.25, 0.50)
EC	(0.5,0.75,1.0)	(0.50,0.75,1)	(0, 0, 0.25)	(0.50,0.75,1)	(0, 0, 0.25)	(0.25,0.5,0.75)	(0, 0, 0.25)
RFP	(0.5,0.75, 1)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.75,1, 1)	(0,0.25,0.5)	(0, 0, 0.25)	(0.25,0.5,0.75)
Qual	(0.50,0.75, 1)	(0,0.25, 0.5)	(0, 0.25, 0.5)	(0.75,1, 1)	(0.25,0.5,0.75)	(0, 0, 0.25)	(0.75, 1, 1)
OE	(0, 0, 0.25)	(0.5,0.75, 1)	(0.75,1, 1)	(0, 0, 0.25)	(0,0.25,0.5)	(0.75, 1, 1)	(0.25,0.5,0.75)
GD	(0.5, 0.75,1)	(0.25,0.5,0.75)	(0, 0, 0.25)	(0.75,1, 1)	(0, 0.25, 0.50)	(0, 0, 0.25)	(0, 0.25, 0.50)
PC	(0.25,0.5,0.75)	(0, 0, 0.25)	(0.25,0.5,0.75)	(0, 0, 0.25)	(0.25,0.5,0.75)	(0, 0.25, 0.50)	(0, 0, 0.25)
Cov	(0.25,0.5,0.75)	(0.75, 1, 1)	(0.25,0.5,0.75)	(0.75, 1, 1)	(0.75, 1, 1)	(0, 0, 0.25)	(0.25,0.5,0.75)

Table 6 Normalized triangular fuzzy numbers of an expert

	A_1	A_2	A_3	A_4	A_5	A_6	A_7
PHS	(0, 0, 0.25)	(0, 0.6, 1.8)	(0, 0, 0.25)	(0.34,0.68,1)	(0,0.34,0.68)	(0.34,0.68,1)	(0.34,0.68,1)
Rel	(0.75,1, 1)	(0.34,0.68,1)	(0.34,0.68,1)	(0,0.34,0.68)	(0,0.34,0.68)	(0, 0, 0.25)	(0, 0.6, 1.8)
Cost	(0, 0, 0.25)	(0.34,0.68,1)	(0,0.34,0.68)	(0.34,0.68,1)	(0, 0.6, 1.8)	(0,0.34,0.68)	(0,0.34,0.68)
EC	(0.34,0.68,1)	(0.34,0.68,1)	(0, 0, 0.25)	(0.34,0.68,1)	(0, 0, 0.25)	(0.25,0.5,0.75)	(0, 0, 0.25)
RFP	(0.34,0.68,1)	(0, 0.6, 1.8)	(0,0.34,0.68)	(0, 0.6, 1.8)	(0, 0.34,0.68)	(0, 0, 0.25)	(0, 0.6, 1.8)
Qual	(0.34,0.68,1)	(0, 0.6, 1.8)	(0,0.34,0.68)	(0, 0.5, 1.5)	(0.25,0.5,0.75)	(0, 0, 0.25)	(0, 0.6, 1.8)
OE	(0, 0, 0.25)	(0.34,0.68,1)	(0, 0.6, 1.8)	(0, 0, 0.25)	(0, 0.34,0.68)	(0.34, 0.68, 1)	(0,0.34,0.68)
GD	(0.50,0.75,1)	(0, 0.6, 1.8)	(0, 0, 0.25)	(0.34,0.68,1)	(0,0.34,0.68)	(0, 0, 0.25)	(0,0.34,0.68)
PC	(0, 0.6, 1.8)	(0, 0, 0.25)	(0,0.6,1.8)	(0, 0, 0.25)	(0.25,0.5,0.75)	(0, 0.25, 0.50)	(0, 0, 0.25)
Cov	(0,0.34,0.68)	(0.34,0.68,1)	(0, 0.6, 1.8)	(0, 0.6, 1.8)	(0, 0.6, 1.8)	(0, 0, 0.25)	(0,0.34,0.68)

include environmental competencies (EC), pollution control (PC), reliability (REL) and green design (GD); technical sub- criteria include operational efficiency (OE) while social sub- criteria include respect for policy (RFP), coverage and public health and safety (PHS).

On the other hand, the available sustainable water supply alternatives considered in this work are desalination, grey water, imported water, water harvesting, borehole, black water and reclaimed water.

Table 5 shows the triangular fuzzy numbers of an expert for the different water supply alternatives with respect to the sustainability factors.

The triangular fuzzy numbers of experts were normalized using CFCS into crisp values as shown in Eqs. (2), (3), (4) and (5). Table 6 shows the normalized triangular fuzzy numbers of an expert in a period.

Table 7 reflects the left and right side normalized values calculated using Eqs. (6) and (7).

Table 8 depicts the normalized crisp values of an expert that was calculated using Eq. (8). The total normalized crisp values were then computed using Eq. (9). Thereafter the crisp values were integrated using Eq. (10).

Same process was employed for all experts, to compute the total normalized crisp values of the performance of the available supply alternatives with respect to the sustainability factors.

In other to estimate the average score for performance of water supply alternatives with respect to relevant sustainability factors, a simple average method was utilized. Table 9 shows the average performances of water supply alternatives respective to specific sustainability factors.

The information on Table 9 was used as input in the TOPSIS model employed in this work.

Using Eq. (11) and data on Table 9, the normalized decision matrix was developed as reflected on Table 10.

The weighted normalized decision matrix was derived using Eq. (12) and data on the normalized decision matrix as shown on Table 11.

After computing the weighted normalized decision matrix, the positive and negative ideal solutions were calculated using Eqs. (13) and (14) and information on Table 11. Then, the separation measures (k_i^+ and k_i^-) were calculated for the water supply alternatives using Eqs. (15) and (16).

The relative closeness to the ideal solutions E_i (**TOPSIS index**) was finally determined using Eq. (17), and this was also employed for ranking of the water supply alternatives.

Table 7 Computed right and left normalized values of triangular fuzzy numbers of an expert

	A_1	A_2	A_3	A_4	A_5	A_6	A_7
PHS	(0, 0, 0.3)	(0.2,0.25,0.33)	(0, 0, 0.3)	(0.66,0.66,0.49)	(0.2, 1, 0.66)	(0.66,0.66,0.49)	(0.66,0.66,0.49)
Rel	(0.75,1, 1)	(0.66,0.66,0.49)	(0.34, 0.68, 1)	(0.2, 1, 0.66)	(0.2, 1, 0.66)	(0, 0, 0.3)	(0.2,0.25,0.33)
Cost	(0, 0, 0.3)	(0.66,0.66,0.49)	(0.2, 1, 0.66)	(0.66,0.66,0.49)	(0.2,0.25,0.33)	(0.2,1,0.66)	(0.2, 1, 0.66)
EC	(0.66,0.66,0.49)	(0.66,0.66,0.49)	(0, 0, 0.3)	(0.66,0.66,0.49)	(0, 0, 0.25)	(0.6, 1, 0.6)	(0, 0, 0.3)
RFP	(0.66,0.66,0.49)	(0.2, 0.25, 0.33)	(0.2, 1, 0.66)	(0.2, 0.25, 0.33)	(0.2, 1, 0.66)	(0, 0, 0.3)	(0.2,0.25,0.33)
Qual	(0.66,0.66,0.49)	(0.2, 0.25, 0.33)	(0,0.34,0.68)	(0, 0.5, 1.5)	(0.6, 1, 0.6)	(0, 0, 0.3)	(0.2,0.25,0.33)
OE	(0, 0, 0.3)	(0.66,0.66,0.49)	(0.2,0.25,0.33)	(0, 0, 0.3)	(0.2, 1, 0.66)	(0.2,1,0.66)	(0.2,1,0.66)
GD	(0.50,0.75,1)	(0.2, 0.25, 0.33)	(0, 0, 0.3)	(0.66,0.66,0.49)	(0.2, 1, 0.66)	(0, 0, 0.3)	(0.2,1,0.66)
PC	(0.2,0.25,0.33)	(0, 0, 0.3)	(0.2,0.25,0.33)	(0, 0, 0.3)	(0.6, 1, 0.6)	(0, 0.25, 0.50)	(0, 0, 0.3)
Cov	(0.2,0.25,0.33)	(0.34, 0.68, 1)	(0.2,0.25,0.33)	(0.2, 0.25, 0.33)	(0.2,0.25,0.33)	(0, 0, 0.3)	(0.2,1,0.66)

Table 8 Total normalized crisp values of fuzzy numbers of an expert

	A_1	A_2	A_3	A_4	A_5	A_6	A_7
PHS	0.44	0.273	0.44	0.876	0.562	0.876	0.876
Rel	0.356	0.876	0.769	0.245	0.378	0.44	0.273
Cost	0.44	0.578	0.781	0.876	0.273	0.282	0.457
EC	0.876	0.523	0.44	0.876	0.391	0.876	0.44
RFP	0.512	0.273	0.273	0.273	0.273	0.44	0.273
Qual	0.48	0.589	0.457	0.562	0.245	0.44	0.273
OE	0.44	0.512	0.391	0.44	0.918	0.697	0.356
GD	0.891	0.273	0.781	0.282	0.523	0.44	0.769
PC	0.273	0.44	0.273	0.457	0.781	0.935	0.44
Cov	0.273	0.457	0.44	0.273	0.273	0.44	0.891

Table 12 shows the calculated separation measures and relative closeness to the ideal solutions which are used for ranking of water supply options.

From Table 12, A_4 (borehole) ranks the highest with respect to the relevant sustainability factors. This is followed by A_2 (water harvesting), and then, A_7 (desalination) ranking third. The least ranked water supply alternative is A_6 (black water).

Based on model results, indications are that borehole water supply option is the preferred available supply option. These outcomes are in harmony with facts that the region typically displays a dynamic equilibrium of water bodies, surrounded by a conglomerate of beaches, fresh water swamps, estuaries and mangrove swamps, with permeable and porous hydrogeological features that are characterized by prolific interlocks of gravel, unconfined sand, clay and shale (Amadi et al. 2014). Structurally, the terrain is unconsolidated, flat, dense vegetation, with well drained rivers and streams that creates a prevalent large reservoir source. This is primarily consequent on the good infiltration capacity of the soils/ground, favored by its flat nature and facilitated by its porosity. Generally, annual rain fall is high, about 2200 mm, with rain falling at almost any time of the year even during dry season. Evapotranspiration ranges around 1000 mm, about 75% of which is believed to recharge the subsurface aquifers. Most streams and rivers are very well drained and overlap most of the significant aquifers in the area, thus more or less feeding them year round, recharging the surface streams/rivers, and hence not necessarily requiring flooding periods for recharge, since an almost influent situation is created naturally.

Table 9 Average performances of water supply alternatives with respect to sustainability factors

	A_1	A_2	A_3	A_4	A_5	A_6	A_7
PHS	0.432	0.569	0.469	0.786	0.654	0.881	0.678
Rel	0.536	0.864	0.889	0.346	0.561	0.445	0.245
Cost	0.443	0.786	0.873	0.912	0.41	0.276	0.446
EC	0.789	0.654	0.566	0.897	0.511	0.851	0.482
RFP	0.623	0.453	0.372	0.346	0.371	0.435	0.245
Qual	0.457	0.765	0.547	0.652	0.433	0.447	0.51
OE	0.479	0.622	0.493	0.459	0.92	0.768	0.345
GD	0.932	0.348	0.817	0.456	0.503	0.543	0.79
PC	0.384	0.401	0.372	0.542	0.751	0.95	0.491
Cov	0.422	0.574	0.541	0.376	0.254	0.547	0.918

Table 10 Normalized decision matrix

	A_1	A_2	A_3	A_4	A_5	A_6	A_7
PHS	0.186624	0.323761	0.219961	0.617796	0.427716	0.776161	0.459684
Rel	0.287296	0.746496	0.790321	0.119716	0.314721	0.198025	0.060025
Cost	0.196249	0.617796	0.762129	0.831744	0.1681	0.076176	0.198916
EC	0.622521	0.427716	0.320356	0.804609	0.261121	0.724201	0.232324
RFP	0.388129	0.205209	0.138384	0.119716	0.137641	0.189225	0.060025
Qual	0.208849	0.585225	0.299209	0.425104	0.187489	0.199809	0.2601
OE	0.229441	0.386884	0.243049	0.210681	0.8464	0.589824	0.119025
GD	0.868624	0.121104	0.667489	0.207936	0.253009	0.294849	0.6241
PC	0.147456	0.160801	0.138384	0.293764	0.564001	0.9025	0.241081
Cov	0.178084	0.329476	0.292681	0.141376	0.064516	0.299209	0.842724

Model results are explicit, and shows borehole water emerging topmost ranked, albeit having a very marginal difference with RWH. Unlike Jaber and Moshen's study using AHP, our approach's employ of a deduction process, encapsulating expert opinions, linguistic scales, TFN and the CFCS method, helped determine core sustainability criteria employed in the modelling. The TFN was useful in erasing the cloud of ambiguity in judgment, hence making for a more reliable and adequate real life decision making process. Additionally, our study incorporated the social sustainability factor in the modelling process, a crucial aspect of sustainability, making for a full stakeholder participation and broader view. Criteria of key importance from Table 11 include COST RFP, COV, PHS and GD. Beyond this, our study employed 50 expert opinions unlike Tahereb et al.'s team who utilized only three, allowing for a more robust analysis. Demonstrably, our approach displays various alternative water supply options and their interplay with crucial sustainability criteria, yielding results that are generally feasible in similar situations. Although borehole water emerged first option, the epileptic power supply in the country places a strain/difficulty in operating boreholes. Hence beyond the current model outcomes, RWH should also be considered a viable alternative option, especially if the issue of acid rain, which was identified from expert interviews, as a major reason for its dilatory/unacceptable adoption is addressed.

Table 11 Weighted normalized decision matrix

	A_1	A_2	A_3	A_4	A_5	A_6	A_7
PHS	1.357	1.272	1.218	1.364	1.224	0.901	0.876
Rel	1.392	0.915	0.889	1.364	0.899	0.445	0.542
Cost	0.927	1.380	1.420	1.427	1.102	0.276	0.446
EC	1.221	1.214	0.967	0.897	1.153	0.851	0.482
RFP	0.875	1.370	0.886	0.346	0.713	0.534	1.002
Qual	1.014	1.370	0.547	0.652	1.114	0.447	0.51
OE	1.024	1.298	1.230	0.459	0.92	0.768	1.135
GD	1.01	1.161	0.719	1.199	0.503	1.302	0.979
PC	0.891	0.891	1.169	0.988	1.273	0.59	0.941
Cov	0.988	1.274	0.541	0.376	0.254	1.304	1.219

Table 12 Total performance and ranking of water supply alternatives

	k_i^-	k_i^+	$k_i^+ + k_i^-$	E_i	Ranking
A_1(Grey water)	0.652	1.224	1.876	0.347	6
A_2(Water harvesting)	1.364	0.915	2.279	0.598	2
A_3(Imported water)	0.897	1.427	2.324	0.385	5
A_4(Borehole)	1.427	0.899	2.326	0.613	1
A_5(Reclaimed water)	0.875	1.37	2.245	0.389	4
A_6(Black water)	0.346	1.102	1.448	0.238	7
A_7(Desalination)	0.967	0.713	1.68	0.575	3

5 Conclusion

We have in this study, considering the unsatisfactory level of water supply in the country conducted an explicit and apt analysis following a deduction process utilizing solicited elite opinions for selecting criteria's crucial in achieving sustainability in water supply, by employing the uniqueness of fuzzy TOPSIS model formulated to decide a preferred choice for an alternative water supply option in Nigeria. The linguistic concept and the CFCS method have been applied, revelations from performance rankings indicates borehole water as the best alternative. The study also considers the role of socioeconomic factors in its analysis, a criteria that is fundamental to society and human judgment. This and environmental factors, linked to atmospheric pollutions (acid rain phenomenon) is identified as a major reason for RWH ranking second, albeit with only a marginal difference. The method employed here is simple and demonstrates ease in decision making whilst applicable to similar terrains or region. The study would be useful for policy makers and indeed all involved in water supply/management/planning field as it permits/enhances apt tradeoff between attributes, simulating between alternatives thus providing improved understanding of differences. This would enable/foster capacity building in weak or complacent areas, hence help develop appropriate alternative strategies.

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