# THE USE OF MULTI-CRITERIA DECISION MAKING ANALYSIS FOR THE SELECTION OF SUITABLE WATER SUPPLY SOURCE FOR EKOSODIN COMMUNITY IN BENIN CITY.

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**ABSTRACT:** The decision to provide water supply to a community requires the consideration of several criteria and alternatives sources of water supply. This is in view of the sensitive nature of water supply scheme and the irreversibility of the project. For the determination of the most suitable water supply source for Ekosodin community, cost, availability, accessibility, infrastructural requirements and health impact of the water to be supplied were selected as controlling criteria while the sources selected include rainwater, borehole, stream and water tanker supply. AHP and TOPSIS which are two multi-criteria analysis methods were used with structured questionnaires to determine the most preferred criterion for selecting the right source of water. Results of analysis showed that health impact with a normalized relative of 47.18% and Positive Ideal value of 7.07 for the AHP and TOPSIS methods respectively was the most preferred criteria. Borehole water source with a composite weight of 41.28% and a relative closeness of 0.75 in the AHP and the TOPSIS came top as the most suitable water source for the study location.
**Keywords: Criteria, Water Sources, AHP, TOPSIS, Health Impact and borehole.**

## 1.0 INTRODUCTION

The importance of water to human existence has been widely covered in literature even though it still invokes inquiries for research. The use of water cut across almost all segments of human endeavours and it is deeply imbedded in our cultural and religious background [1]. While there is some variability of water use, the predominant consumption of water, especially for domestic purpose is equal for all humans no matter their location of residence. Investigations have shown that there is a stark contrast in the development of water infrastructure between the urban areas and the rural and semi urban areas of the society. The urban areas, which more often than not requires huge amount of capital to source for and explore water resources, tends to have a more developed and functional water infrastructure than the rural area and semi urban areas of the society. The rural areas are usually located close to fresh surface water resource and in some cases, lavish and untapped ground water resources.

The selection of the right water supply source for a location requires rigorous analysis to evaluate all the alternatives and extant conditions of the location for which water supply is required. The criteria for the determination of the source of water are usually numerous, with each having its pros and cons. Some of these criteria include power supply, water demands, population, cost of development, treatment requirements, quantity of the water in reserve; pollution propensity and the likely water transmission or distribution requirements. The use of the manual approach for the selection of suitable water supply source using the various criteria is excessively time consuming and usually lends itself to lots of assumption, resulting in over design or under designed of the water supply systems. Decision support software helps in the processes of selecting the most suitable water sources while considering the various peculiarities of a location.

This paper intends to establish by multi-criteria analysis the most veritable source of water for Ekosodin community of Ovia North East Local Government Area of Edo state using TOPSIS and AHP as decision support tools for the evaluation of the various water supply options. It also examines the various options available to residents and determine the best choice having established suitable criteria to ensure sustainability of the selected choice of water supply for residents of the study location.

## 2.0 LITERATURE REVIEW

Multi-Criteria analysis as a technique in operation research emerged between 1960 and 1970 during the period of WWII. MCA describe a conglomeration of techniques with the capacity to improve the transparency, auditability and the rigorous evaluation of decision [2, 3]. MCA has established application in the field of energy planning [4], agriculture [5], natural resources management application [6] and financial management [7] etc.

Comparative assessment of the various techniques of MCA showed that no one technique inherently gives a better solution than the others [2]. Every approach is unique with its peculiar limitations.

MCA is a decision support model that contains a set of decision options, ranked and scored by the decision maker. It also consists of a set of typically measured criteria of different units with a set of performance measure. Given that they are n decision options worth considering and m criteria, the minimum requirements for the MCA model is in the range of $m \geq 2$ and $n \geq 2$. Take P as the evaluation matrix and S as the dimensional weight vector with each weight assigned to a criterion, the algorithm that describes the ranking of the function comprising P and S is given as

$$r_i = f_1[P, S] \qquad (1)$$

Where r = rank; $f_1$= relational function of ranked criteria; i = decision component.

The preference score option (u) of the decision component *i* which describes the implication of the dimensional weight and the evaluation matrix on the overall decision process is given as

$$u_i = f_2[P, S] \qquad (2)$$

Where u = score; $f_2$= relational function of preference criteria; i = decision component.

According to **[8],** the stages of analysis for Multi Criteria Analysis are presented in the flow chart in Figure 1.

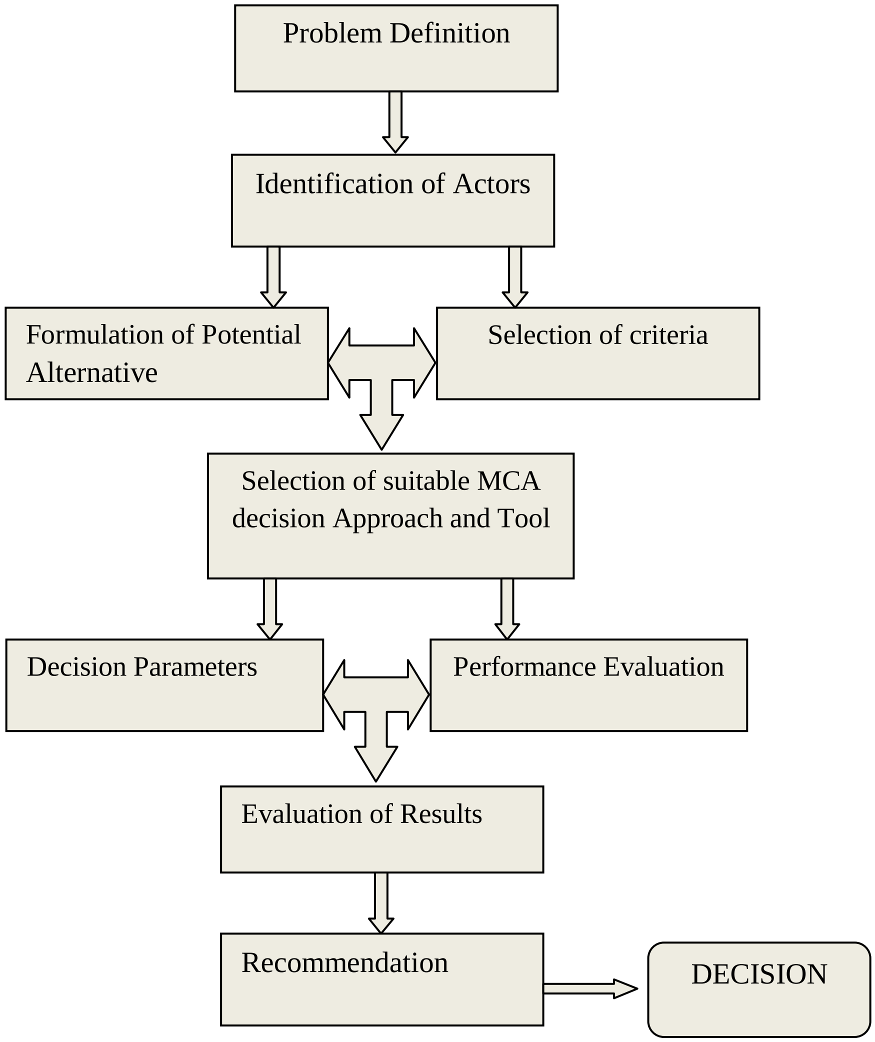


**Figure 1: Stages of Multi-Criteria Analysis [8]**

The process in Figure 1 is usually iterative and best managed using a computer software specially tailored for the task.

### 2.1 Types of Multi-Criteria Analysis

Some of the major types of multi criteria analyses are described below:

**2.1.1 Multi Criteria value Function:** This comprises the weighted summation and weighted multiplication. The weighted summation performance function relating the weight x and the score y ascribed to each option of a criteria is given by

$$u_i = \sum_{j=1}^{m} x_{ij} y_j \tag{3}$$

Where $y_j$ is the non-negative weight and sums up to 1, $x_{ij}$ is a transformed performance score for x on a scale of 0 to 1; 1 indicate the best performance. In weighted multiplication, the summation aspect is replaced with multiplication. This implies that the function is non-compensatory especially where one of the weight or score is zero; the entire performance will be zero due to multiplication operator as against the summation operator.

**2.1.2 Distance to Ideal Point Method:** This methods involves the identification of the ideal and the non-ideal point value of the criteria. In the absence of these defined point values, the minimum and maximum criterion values are considered instead. Two predominant techniques of this method of multi criteria analysis are the compromise programming [ 9, 10] and TOPSIS [11]

**2.1.3 Pairwise Comparison:** This approach to MCA comprises Analytical Hierarchy process [12], Measurement of Attractiveness by Categorical Based Evaluation technique [13] and the Analytical Network process [14]. This approach entails making comparisons between the criteria and the alternatives in every unique pair giving $\frac{n(n-1)}{2}$ comparison. The comparisons are made to attain criteria weight and performance score using scaling systems to rank and weigh a chosen option after several analysis.

**2.1.4 Outranking Approach:** The outranking approach comprise of the Preference Ranking Organization Method for Enrichment Evaluation [15] and the Elimination and choice expressing reality method [16, 17]. They entails identifying every pair of decision options i and j resulting to $n^2 - n$ pairs in total. This approach makes use of the criteria weight to determine how one option i outperforms another option j.

**2.1.5 Fuzzy Set Analysis:** The fuzzy set theory was introduced to MCA in the mid-nineties [18, 19]. It entails a slow but sure transition of items in a multiple set from one class to another. It is especially suited to solving uncertainty problems [2].

**2.1.6 Tailored method:** This involves the generation of a new MCA function by the adaptation of an existing MCA function through alteration and re-arrangement of algorithm in the function. This leads to practically limitless possibility in the generation of new ideas from a simple mathematical combination of the rank and weight of a set of alternatives and criteria to the decision maker.

## 2.2 AHP and TOPSIS

The two methods used in this study were Analytic hierarchy process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). These methods will be explained in some details.

### 2.2.1 Analytic hierarchy process (AHP) method

The AHP procedure of multi criteria analysis makes uses of pair wise comparisons between each criterion. It categories the options based on a scaling system. One of such scale used in the AHP system is the Saaty scale [14]. A sample scale typically used for criteria categorization is presented in Table 1

**Table I: Saaty Scale of Pair-Wise Comparison**

| Intensity of Importance | Definition | Explanation |
|---|---|---|
| 1 | Equal importance | Two activities contribute equally to the objective |
| 2 | Weak or slight | |
| 3 | Moderate importance of one factor over another | Experience and judgment slightly favour one activity over another |
| 4 | Moderate plus | |
| 5 | Strong importance | Experience and judgment strongly favour one activity over another |
| 6 | Strong plus | |
| 7 | Very strong importance | An activity is favoured very strongly over another |
| 8 | Very very strong | |
| 9 | Extreme importance | The evidence favouring one activity |

**Source:[20]**

The comparison of each factor pair of criteria was described in terms of integer values from 1 to 9, where higher number means the chosen factor is considered more important in greater degree than other factors being compared. In using AHP, the work are usually broken in to the following steps:

1. Decomposition of the decision-making problem into a hierarchy.
2. Creation of pair wise comparisons and establishment of priorities among the elements in the hierarchy.
3. Synthesis of judgments in order to obtain the sets of overall score or weights for achieving the goal.
4. Evaluation of the consistency of judgments.

The development of the weights for the criteria involves creating a pair-wise comparison for each criteria; normalizing the resulting matrix; taking the mean of each row element in the matrix to obtain the criteria rating and evaluating the consistency ratio of other matrix rows. This is closely followed by developing ratings for each criterion; compute the weighted average for each decision alternative and choosing those decisions with the highest scores.

In order to derive the consistency ratio that is used to ascertain the reliability of judgments in the AHP process, the principal Eigen value, consistency index and Random index are derived. These parameters are given as:

$$\text{Principal Eigen Value}\left(\lambda_{\max}\right) = \left(\sum_{j} C_I\right).W_J \qquad (4)$$

$$Consistency\ Index\ \left(CI\right) = \frac{\lambda_{\max} - n}{n-1} \qquad (5)$$

Where $\lambda_{max}$ = Principal Eigen value; n = order of matrix; C = column of evaluation matrix; W = weighted average, *i* and *j* are row and column respectively. The consistency index usually reflects the reliability of the selected judgment.

Random Index (RI) which is the consistency index of a randomly generated pair wise comparison matrix is presented in tabular form and shown in the Table 2.

**Table 2: Average Random Index (RI)**

| SIZE OF MATRIX (N) | RANDOM |
|---|---|
| 1 | 0 |
| 2 | 0 |
| 3 | 0.58 |
| 4 | 0.9 |
| 5 | 1.12 |
| 6 | 1.24 |
| 7 | 1.32 |
| 8 | 1.41 |
| 9 | 1.45 |
| 10 | 1.49 |

**Source:[17]**

Therefore the consistency ratio is given as

$$Consistency\ ratio = \frac{CI}{RI} \qquad (6)$$

Where CI and RI are as stated in equation (5) and Table 2. For consistency of judgment, CR < 0.1

### 2.2.2 Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) Method

TOPSIS is an approach to identify an alternative which is closest to the ideal solution and farthest to the negative ideal solution in a multi-dimensional computing space [21]. This method principally considers three types of attributes:

1. Qualitative benefit attributes/criteria
2. Quantitative benefit attributes
3. Cost attributes or criteria

In TOPSIS method two artificial alternatives are often hypothesized. These include the ideal positive alternative and the Ideal negative alternative. The ideal positive alternative deals with the best level of all the attributes considered. This reverse is the case for the Ideal negative alternatives. Like the AHP method, the TOPSIS methods also uses a scaling system with the + and – sign notations representing the level of importance of each attributes.

TOPSIS assumes that they are m alternatives and n criteria and that they is a score for each option with respect to each mentioned criterion. Let $x_{ij}$ be score of option i with respect to criterion j. Therefore the evaluation matrix (X) is given as

$$X = x_{ij}.[m \times n] \qquad (7)$$

Given that J is the set of benefit criteria and J' is the set of negative criteria, the procedures for using TOPSIS as a MCA tool follow thus:

1. Standardize the decision matrix: This step transforms various dimensions attribute into their non-dimensional variants, allowing comparisons across criteria. The standardized score ($r_{ij}$) is expressed mathematically as:

$$r_{ij} = \frac{x_{ij}}{\sum x^2_{ij}} \; for \; i = 1, \ldots, m; \; j = 1, \ldots, n \qquad (8)$$

2. Construct the weighted standardized decision matrix: This occurs by multiplying the decision variables by their respective weights to obtain a new normalized weighted decision matrix ($v_{ij}$). Assuming that a set of weights exist for each criteria $w_j$ for j = 1,..…n. the new matrix ($v_{ij}$) is given as

$$\mathbf{v_{ij}} = \mathbf{w_j} \; x \; \mathbf{r_{ij}} \qquad (9)$$

3. Determine the ideal positive and ideal negative solutions. The positive ideal solution (A*) is a collection of the best values with respect to each criterion in the weighted normalized decision matrix while the negative ideal solution (A') is a collection of the worst values in respect to each criterion in the weighted normalized decision matrix. This is expressed as

$$Ideal \; positive \; solution \; A* = \left\{ v_1^*, \ldots, v_n^* \right\}, \qquad (10)$$

where $v_{ij}^* = \{ \; max \; \left( v_{ij} \right) \; if \; j \in J'; min \; \left( v_{ij} \right) \; if \; j \in J' \; \}$

$$Ideal \; Negative \; solution \; A* = \left\{ v_1^{'}, \ldots, v_n^{'} \right\}, \qquad (11)$$

where $v_{ij}^{'} = \{ \; \min \; \left( v_{ij} \right) \; if \; j \in J'; \max \; \left( v_{ij} \right) \; if \; j \in J' \; \}$

4. Calculate the separation measures (S) for each alternative. The separation from the ideal alternative is given in equations (12) and (13).

$$S_{ij}^* = \left[ \sum \left( v_{ij}^* - v_{ij} \right)^2 \right]^{\frac{1}{2}} \; i = 1, \ldots, m \qquad (12)$$

$$S_{ij}^{'} = \left[ \sum \left( v_{ij}^{'} - v_{ij} \right)^2 \right]^{\frac{1}{2}} \; i = 1, \ldots, m \qquad (13)$$

5. Calculate the relative closeness $C_i^*$ to the ideal solution as

$$C_i^* = \frac{S'_i}{S_i^* + S'_i} \; ; \quad 0 < C_i^* < 1 \qquad (14)$$

Select the option of $C_i^*$ that is closest to 1 as the preferred relative closeness.

## 3.0 MATERIAL AND METHODS

### 3.1 Description of Study Area

Ekosodin is a community located in Ovia North East Local Government Area of Edo State. It is predominantly resident by students of the University of Benin where outside-campus hostels have been provided by private individuals for commercial purposes. Preliminary assessments of the water condition of Ekosodin indicated that they are basically four sources of water for the community and they include: Rainwater, drilled Borehole, stream and commercial water tanker supply. The rainwater and borehole drilling constitute the major sources of water for the exterior location of the community while stream and commercial water tanker constitute the predominant source of supply for the interior location of the community.

### 3.2 Methodology

Expert survey on the water condition of Ekosodin was carried out by consulting and interviewing relevant stakeholders involved in water supply such as water managers in Benin City water Board Corporation, water vemdors, tenants and landlords and tradition leaders of Ekosodin community. From this activities, five (5) criteria that facilitate decision making on the source of water supply for each developmental project were established. These include cost, health impact, accessibility, availability and infrastructural requirements. The rating scale of the criteria commences from not important at all, important, neutral, importance and very important in the order of 1 to 5 respectively.

Questionnaires were then distributed to water experts and decision makers in order to rate the importance of each source with reference to the criteria. The ordinal scale (--/++) was used in scoring the alternative sources of water with respect to the criteria. The scale chosen is shown in Table 3:

**Table 3: Ordinal scale**

| | |
|---|---|
| **++** | Representing the Big positive degree of importance =5 |
| **+** | Representing the small positive degree of importance = 4 |
| **0** | Representing no effect , degree of importance = 3 |
| **-** | Representing some negative effect =2 |
| **--** | Representing Big negative effect = 1 |

The results of the stated conditions were subjected to TOPSIS and AHP analyses from where the most suitable decision will be taken given the different criteria and the alternatives sources of water supply. In the AHP method, questionnaires were handed to six group of decision makers comprising the state water corporation, the Local Council water supply official, Ekosodin traditional rulers, landlords and tenants tagged DM1 to DM6 respectively. For each criterion, computation was carried out to determine the consistency check in line with equation (6) for each decision maker as well for each criteria. In each case, pair-wise comparison of the criteria for weight determination and normalized weight for each criteria was carried out for consistency check in line with equation (6).

The procedure for TOPSIS computation was carried out in line with equations (8) - (14). In the TOPSIS method, a ranking in the order of 1 – 10 was first carried out by the respondent as an initial step in filling the questionnaire. The average weight for each criterion was used to prepare another questionnaire from which results were used to compute the negative and positive standard ideal solution. The relative closeness of the ideal solution was also computed from which the final solution is obtained.

## 4.0 RESULTS AND DISCUSSION

Results shall be presented for the AHP method and for the TOPSIS method

### 4.1 AHP Method

The average results of pair-wise comparison from the questionnaires distributed to the six (6) decision makers (DM) and the computations of the weights are presented in Tables 4 to 10. From the standpoint of DM1 it was observed that there were equal emphases placed on infrastructural requirement and accessibility with a total sum of 25 each. This was closely followed by availability and accessibility, with each having a total sum of 5.29. The least consideration was placed on health impacts. Similar trends also occurred in DM2 with each having an almost equal emphases placed on availability and health impact that ranked the lowest. Accessibility is second to an equal of ranking of cost and infrastructural requirements.

While there was no equality between any criteria in DM3, they were closeness between accessibility and cost which is seconding infrastructural requirement. The lowest ranked criteria was health impact which was followed by availability with a summation value of 1.79 and 4.83 respectively. In DM4, cost was the dominant criteria which were orderly followed by infrastructural requirement, accessibility, availability and health impacts. This pattern was repeated in DM5 with reduced summation values for cost and availability. Similar trend also occurred in DM6 with strong resemblance to DM4. Health impact became the lowest ranking for decision making, indicating people cared less of the potability of the water they drink but instead on the cost and infrastructural requirement in determining the source of water supply for a location. Computational output of the consistency check for all the decision makers are presented in Table 11. The consistency ratios were between 0.0417 and 0.0945 indicating uniformity of opinion by the decision makers.

**Table 4: Pair-Wise Comparison of DM1 Questionnaire**

| **Criteria** | **Cost** | **Health Impact** | **Accessibility** | **Availability** | **Infrastructural Requirement** |
|---|---|---|---|---|---|
| Cost | 1 | 1/9 | 1/7 | 1/7 | 1 |
| Health Impact | 9 | 1 | 3 | 3 | 9 |
| Accessibility | 7 | 1/3 | 1 | 1 | 7 |
| Availability | 7 | 1/3 | 1 | 1 | 7 |
| Infrastructural requirement | 1 | 1/9 | 1/7 | 1/7 | 1 |
| SUM | 25 | 1.89 | 5.29 | 5.29 | 25 |

**Table 5: Pair-Wise Comparison of DM2 Questionnaire**

| CRITERIA | Cost | Health Impact | Accessibility | Availability | Infrastructural Requirement |
|---|---|---|---|---|---|
| Cost | 1 | 1/9 | 1/7 | 1/9 | 1 |
| Health Impact | 9 | 1 | 5 | 1 | 9 |
| Accessibility | 7 | 1/5 | 1 | 1/3 | 7 |
| Availability | 9 | 1 | 3 | 1 | 9 |
| Infrastructural requirement | 1 | 1/9 | 1/7 | 1/9 | 1 |
| SUM | 27 | 2.42 | 9.29 | 2.56 | 27 |

**Table 6: Pair-Wise Comparison of DM3 Questionnaire**

| Criteria | Cost | Health Impact | Accessibility | Availability | Infrastructural Requirement |
|---|---|---|---|---|---|
| Cost | 1 | 1/7 | 3 | 1/3 | 3 |
| Health Impact | 7 | 1 | 5 | 3 | 9 |
| Accessibility | 1/3 | 1/5 | 1 | 1/3 | 3 |
| Availability | 3 | 1/3 | 3 | 1 | 5 |
| Infrastructural requirement | 1/3 | 1/9 | 1/3 | 1/5 | 1 |
| SUM | 11.67 | 1.79 | 12.33 | 4.87 | 21 |

**Table 7: Pair-Wise Comparison of DM4 Questionnaire**

| Criteria | Cost | Health Impact | Accessibility | Availability | Infrastructural Requirement |
|---|---|---|---|---|---|
| Cost | 1 | 1/9 | 1/5 | 1/7 | 1/3 |
| Health Impact | 9 | 1 | 5 | 3 | 7 |
| Accessibility | 5 | 1/5 | 1 | 1/3 | 3 |
| Availability | 7 | 1/3 | 3 | 1 | 5 |
| Infrastructural requirement | 3 | 1/7 | 1/3 | 1/5 | 1 |
| SUM | 25 | 1.79 | 9.53 | 4.68 | 16.33 |

**Table 8: Pair-Wise Comparison of DM5 Questionnaire**

| Criteria | Cost | Health Impact | Accessibility | Availability | Infrastructural Requirement |
|---|---|---|---|---|---|
| Cost | 1 | 1/9 | 1/5 | 1/7 | 1 |
| Health Impact | 9 | 1 | 9 | 1 | 9 |
| Accessibility | 5 | 1/9 | 1 | 1/3 | 1 |
| Availability | 7 | 1 | 3 | 1 | 5 |
| Infrastructural requirement | 1 | 1/9 | 1 | 1/5 | 1 |
| SUM | 23 | 2.33 | 14.2 | 2.68 | 17 |

**Table 9: Pair-Wise Comparison of DM6 Questionnaire**

| Criteria | Cost | Health Impact | Accessibility | Availability | Infrastructural Requirement |
|---|---|---|---|---|---|
| Cost | 1 | 1/9 | 1/3 | 1/7 | 1 |
| Health Impact | 9 | 1 | 7 | 1 | 7 |
| Accessibility | 3 | 1/7 | 1 | 1 | 3 |
| Availability | 7 | 1 | 1 | 1 | 5 |
| Infrastructural requirement | 1 | 1/7 | 1/3 | 1/5 | 1 |
| SUM | 21 | 2.40 | 9.67 | 3.34 | 17 |

### 4.1.1 Normalized Relative Weight of Decision

The normalized relative weight for all the decision makers are presented in Table 10.

**Table 10: Normalized Relative Weights for Decision Makers**

| Criteria | DM1 | DM2 | DM3 | DM4 | DM5 | DM6 | Average | % |
|---|---|---|---|---|---|---|---|---|
| Cost | 1/26 | 1/28 | 1/8 | 3/86 | 1/23 | 4/87 | **5/93** | 5.3781 |
| Health Impact | 31/65 | 2/5 | 12/23 | 1/2 | 33/70 | 26/57 | **42/89** | 47.1848 |
| Accessibility | 2/9 | 1/6 | 2/23 | 9/67 | 8/77 | 5/32 | **8/55** | 14.5302 |
| Availability | 2/9 | 14/39 | 19/84 | 19/73 | 10/31 | 11/38 | **7/25** | 27.9986 |
| Infrastructural Requirement | 1/26 | 1/28 | 4/97 | 4/59 | 1/17 | 5/96 | 3/61 | 4.9083 |
| SUM | 1 | 1 | 1 | 1 | 1 | 1 | **1** | 100 |

### 4.1.2 Consistency Check

Consistency check carried using equations (4) – (6) gave the following results for all the decision makers are presented in Table 11.

**Table 11: Consistency Check for Decision Makers**

| Consistency parameters | DM1 | DM2 | DM3 | DM4 | DM5 | DM6 |
|---|---|---|---|---|---|---|
| $\lambda_{max}$ | 5.1867 | 5.3799 | 5.4155 | 5.3739 | 5.4393 | 5.4232 |
| CI | 0.0467 | 0.0950 | 0.1039 | 0.0935 | 0.1098 | 0.1058 |
| CR | 0.0417 | 0.0848 | 0.0928 | 0.0835 | 0.0981 | 0.0945 |

Pair-wise comparison of the data obtained from the various group of decision makers showed that more premium was placed on the quality of water which is emphasized by the high percentage value obtained for public health (or health Impact) in the normalized weight matrix. This was followed by availability in terms of sustained water supply to meet yearning demand. Least premium was placed on the cost of the project as a criteria for selecting a suitable source of water supply. Computation revealed that all decision making groups passed the consistency test which is an indication of the uniformity of opinion of the respondents in each group.

### 4.1.3 Pair-wise Comparison of Alternatives

a) **Cost:** The pair-wise comparison and normalized comparison matrices of the cost criteria for selecting water supply sources are presented in Tables 12 and 13 respectively. Consistency ratio was computed to be 0.0654 which is less than 0.1 required to indicate inconsistency.

**Table 12: Average pair-wise comparison Matrix with respect to Cost**

| Choice | Rainwater Harvesting | Stream | Borehole | Water Tanker |
|---|---|---|---|---|
| Rainwater harvesting | 1 | 5 | 3 | 1/3 |
| Stream | 1/5 | 1 | 1/3 | 1/7 |
| Borehole | 1/3 | 3 | 1 | 1/5 |
| Water tanker | 3 | 7 | 5 | 1 |
| Sum | 4.53 | 16.00 | 9.33 | 1.68 |

**Table 13: Normalized Pair-wise comparison matrix with respect to Cost**

| Choice | Rainwater Harvesting | Stream | Borehole | Water Tanker | Sum | Weights |
|---|---|---|---|---|---|---|
| Rainwater harvesting | 11/50 | 22/71 | 8/25 | 1/5 | 1.05 | **0.2633** |
| Stream | 1/25 | 3/50 | 1/25 | 1/11 | 0.23 | **0.0569** |
| Borehole | 4/57 | 15/79 | 10/91 | 3/25 | 0.49 | **0.1219** |
| Water tanker | 33/50 | 11/25 | 27/50 | 3/5 | 2.23 | **0.5579** |
| Sum | 1 | 1 | 1 | 1 | | |

b) **Health Impact:** The pair-wise comparison and normalized pair-wise matrix for health impact criteria in relation to selected water supply sources are presented in Tables 14 and 15 respectively. $\lambda_{max}$, CI and CR were calculated to be 4.1608, 0.0536 and 0.0596 respectively. The computed CR value was consistent in this instance.

**Table 14: Average pair-wise comparison Matrix with respect to Health Impact**

| CHOICE | Rainwater harvesting | Stream | Borehole | Water tanker |
|---|---|---|---|---|
| Rainwater harvesting | 1 | 5 | 1/3 | 1 |
| Stream | 1/5 | 1 | 1/9 | 1/5 |
| Borehole | 3 | 9 | 1 | 5 |
| Water tanker | 1 | 5 | 1/5 | 1 |
| Sum | 5.20 | 20 | 1.64 | 7.20 |

**Table 15: Normalized Pair-wise comparison matrix with respect to Health Impact**

| Choice | Rainwater Harvesting | Stream | Borehole | Water Tanker | Sum | Weights |
|---|---|---|---|---|---|---|
| Rainwater Harvesting | 15/79 | 1/4 | 1/5 | 7/50 | 0.78 | **0.1960** |
| Stream | 1/25 | 1/20 | 4/57 | 2/67 | 0.18 | **0.0460** |
| Borehole | 29/50 | 9/20 | 36/59 | 20/29 | 2.33 | **0.5824** |
| Water Tanker | 15/79 | 1/4 | 3/25 | 7/50 | 0.70 | **0.1757** |
| Sum | 1 | 1 | 1 | 1 | | |

c) **Accessibility:** Pair-wise comparison and normalized matrix for accessibility criteria of selected water supply sources are presented in Tables 16 and 17 respectively. The consistency check parameters such as $\lambda_{max}$, CI and CR have values of 4.0873, 0.0291 and 0.0323 respectively.

**Table 16: Average pair-wise comparison Matrix with respect to Accessibility**

| Choice | Rainwater Harvesting | Stream | Borehole | Water Tanker |
|---|---|---|---|---|
| Rainwater harvesting | 1 | 7 | 1 | 5 |
| Stream | 1/7 | 1 | 1/7 | 1 |
| Borehole | 1 | 7 | 1 | 3 |
| Water tanker | 1/5 | 1 | 1/3 | 1 |
| Sum | 2.34 | 16 | 2.48 | 10 |

**Table 17: Normalized Pair-wise comparison matrix with respect to Accessibility**

| Choice | Rainwater Harvesting | Stream | Borehole | Water Tanker | Sum | Weights |
|---|---|---|---|---|---|---|
| Rainwater harvesting | 0.43 | 0.44 | 0.40 | 0.50 | 1.77 | **0.4420** |
| Stream | 0.06 | 0.06 | 0.06 | 0.10 | 0.28 | **0.0703** |
| Borehole | 0.43 | 0.44 | 0.40 | 0.30 | 1.57 | **0.3920** |
| Water tanker | 0.09 | 0.06 | 0.13 | 0.10 | 0.38 | **0.0956** |
| Sum | 1 | 1 | 1 | 1 | | |

d) **Availability: T**he pair-wise comparison and normalized matrix formulated when the availability of water supply was related to each of the selected water supply sources are presented in Tables 18 and 19. The consistency ratio of 0.0148 was comparatively better than for cost, health impact and availability.

**Table 18: Average pair-wise comparison Matrix with respect to Availability**

| Choice | Rainwater Harvesting | Stream | Borehole | Water Tanker |
|---|---|---|---|---|
| Rainwater harvesting | 1 | 1/9 | 1/5 | 1 |
| Stream | 9 | 1 | 3 | 9 |
| Borehole | 5 | 1/3 | 1 | 3 |
| Water tanker | 1 | 1/9 | 1/3 | 1 |
| Sum | 16 | 1.56 | 4.53 | 14 |

**Table 19: Normalized Pair-wise comparison matrix with respect to Availability**

| Choice | Rainwater Harvesting | Stream | Borehole | Water Tanker | Sum | Weights |
|---|---|---|---|---|---|---|
| Rainwater harvesting | 3/50 | 4/57 | 1/25 | 4/57 | 0.25 | **0.0624** |
| Stream | 14/25 | 16/25 | 33/50 | 16/25 | 2.51 | **0.6275** |
| Borehole | 22/71 | 17/81 | 11/50 | 17/81 | 0.96 | **0.2404** |
| Water tanker | 3/50 | 4/57 | 4/57 | 4/57 | 0.28 | **0.0697** |
| Sum | 1 | 1 | 1 | 1 | | |

e) **Infrastructural Requirement:** Results of pair-wise comparison and normalized matrix of the infrastructural requirement for each selected water supply sources are presented in Tables 20 and 21. The values of the consistency parameters such as $\lambda_{max}$, CI and CR were 4.2402, 0.0801 and 0.089 respectively.

**Table 20: Average pair-wise comparison Matrix with respect to Infrastructural Requirement**

| Choice | Rainwater Harvesting | Stream | Borehole | Water Tanker |
|---|---|---|---|---|
| Rainwater harvesting | 1 | 5 | 1 | 1/5 |
| Stream | 1/5 | 1 | 1/3 | 1/7 |
| Borehole | 1 | 3 | 1 | 1/5 |
| Water tanker | 5 | 7 | 5 | 1 |
| Sum | 7 .20 | 16 | 7.33 | 1.54 |

**Table 21: Normalized Pair-wise comparison matrix with respect to Infrastructural Requirement**

| Choice | Rainwater Harvesting | Stream | Borehole | Water Tanker | Sum | Weight |
|---|---|---|---|---|---|---|
| Rainwater Harvesting | 7/50 | 22/71 | 7/50 | 3/23 | 0.72 | **0.1793** |
| Stream | 2/67 | 3/50 | 1/20 | 1/11 | 0.23 | **0.0571** |
| Borehole | 7/50 | 15/79 | 7/50 | 3/23 | 0.59 | **0.1481** |
| Water Tanker | 20/29 | 11/25 | 17/25 | 13/20 | 2.46 | **0.6155** |
| Sum | 1 | 1 | 1 | 1 | | |

The average relative normalized weight of each criterion was paired against the water supply source by multiplication to obtain the composite weight of the criteria given the selected sources (see Table 22).

**Table 22: Composite Weight of Water Sources with Respect to Criteria of Selection**

| **Alternative Sources** | **Cost** (0.0538) | **Health Impact** (0.4718) | **Accessibility** (0.1453) | **Availability** (0.2800) | **Infrastructural Requirement** (0.0491) | **Composite Weigh (%)** |
|---|---|---|---|---|---|---|
| Rainwater harvesting | 26.3345 | 19.5975 | 44.2044 | 6.2369 | 17.9346 | **19.7128** |
| Stream | 5.6890 | 4.5952 | 7.0292 | 62.7495 | 5.7081 | **21.3447** |
| Borehole | 12.1873 | 58.2369 | 39.2044 | 24.0415 | 14.8096 | **41.2890** |
| Water tanker | 55.7892 | 17.5705 | 9.5620 | 6.9722 | 61.5478 | **17.6534** |

Pair-wise comparison for critical assessment of each criteria relating to the selected sources of water supply indicated that borehole source was the preferred water option of the location. This is in view of the fact that it meets the health impact criteria by showing consistency and having the highest composite weight of all the selected alternatives. Borehole water supply was followed in the order of preference by stream, rainwater with the water tanker supply being considered as the least preferred water supply source.

### 4.2 TOPSIS Method

Table 23 shows the average weight of the criteria for the first questionnaire to assess the premium placed on each criterion by respondents.

**Table 23: Average Weights of the Criteria**

| S/N | Criteria | Average Weight |
|---|---|---|
| 1 | Health Impact | 10 |
| 2 | Cost | 8 |
| 3 | Availability | 8 |
| 4 | Accessibility | 7 |
| 5 | Infrastructural Requirement | 4 |

The average pair-wise results for the second questionnaire which was distributed to ascertain the most suitable and efficient source of water for each of the criterion considered are presented in Table 24. The ordinal scale was used to rate and then convert the numbers to suitable forms for further calculations. The standard decision matrix and the weighted standardized matrix computed using equations (8) and (9) are presented in Tables 25 and 26 respectively. Values for the ideal positive and ideal negative ideal solutions as computed by equations (10) and (11) are presented in Table 27. These values indicated that health impact, being the highest positive ideal solution, was the most preferred criterion for water source selection while cost being the highest negative solution was the least preferred criteria.

The separation from the ideal positive and ideal negative solutions as computed by equations (12) and (13) are presented in Tables 28 and 29. This served as input for the computation of the relative closeness as presented in Table 30. The relative closeness value of borehole water supply was the closest to 1, implying the preferred choice of water source. This was followed in the order of preference from stream, rainwater to water tanker supply.

**Table 24: Average Standardized Decision Values**

| Criteria/ Alternative Sources | Rainwater Harvesting | Stream | Borehole | Water Tanker |
|---|---|---|---|---|
| Cost | 4.00 | 2.50 | 3.00 | 4.25 |
| Impact on Public Health | 3.00 | 2.00 | 4.25 | 2.25 |
| Accessibility | 4.25 | 3.00 | 3.00 | 2.50 |
| Availability | 2.50 | 5.00 | 4.50 | 2.00 |
| Infrastructural Requirement | 4.75 | 4.25 | 4.50 | 5.00 |

**Table 25: Standardized Decision Matrix**

| Criteria/ Alternative Sources | Rainwater Harvesting | Stream | Borehole | Water Tanker | Criteria Weight |
|---|---|---|---|---|---|
| Cost | 0.57 | 0.36 | 0.43 | 0.61 | 8 |
| Impact on Public Health | 0.50 | 0.33 | 0.71 | 0.37 | 10 |
| Accessibility | 0.65 | 0.46 | 0.46 | 0.38 | 7 |
| Availability | 0.34 | 0.67 | 0.60 | 0.27 | 8 |
| Infrastructural Requirement | 0.51 | 0.46 | 0.49 | 0.54 | 4 |

**Table 26: Weighted Standardized Decision Matrix**

| Criteria/ Alternative Sources | Rainwater Harvesting | Stream | Borehole | Water Tanker |
|---|---|---|---|---|
| Cost | 4.56 | 2.85 | 3.42 | 4.84 |
| Impact on Public Health | 4.99 | 3.33 | 7.07 | 3.74 |
| Accessibility | 4.57 | 3.23 | 3.23 | 2.69 |
| Availability | 2.68 | 5.37 | 4.83 | 2.15 |
| Infrastructural Requirement | 2.05 | 1.83 | 1.94 | 2.16 |

**Table 27: Values for Ideal and Negative Ideal Solutions**

| Criteria | Ideal Positive Solution | Ideal Negative Solution |
|---|---|---|
| Cost | 2.85 | 4.84 |
| Health Impact | 7.07 | 3.33 |

| | | |
|---|---|---|
| Accessibility | 4.57 | 3.23 |
| Availability | 5.37 | 2.15 |
| Infrastructural | 2.16 | 1.83 |

**Table 28: Separation from Positive Ideal Solution ($S_1$)**

| Criteria/ Alternative Sources | Rainwater Harvesting | Stream | Borehole | Water Tanker |
|---|---|---|---|---|
| Cost | 2.91 | 0.00 | 0.32 | 3.97 |
| Impact on Public Health | 4.32 | 14.01 | 0.00 | 11.07 |
| Accessibility | 0.00 | 1.80 | 1.80 | 3.53 |
| Availability | 7.21 | 0.00 | 0.29 | 10.38 |
| Infrastructural Requirement | 0.01 | 0.11 | 0.05 | 0.00 |
| **$S_1$** | **3.8023** | **3.9990** | **1.5680** | **5.3804** |

**Table 29: Separation from Negative Ideal Solution ($S_2$)**

| Criteria/ Alternative Sources | Rainwater Harvesting | Stream | Borehole | Water Tanker |
|---|---|---|---|---|
| Cost | 0.08 | 3.97 | 2.02 | 0.00 |
| Impact on Public Health | 2.76 | 0.00 | 14.00 | 0.17 |
| Accessibility | 1.81 | 0.00 | 0.00 | 0.29 |
| Availability | 0.29 | 10.36 | 7.19 | 0.00 |
| Infrastructural Requirement | 0.05 | 0.00 | 0.01 | 0.11 |
| **$S_2$** | **2.23** | **3.79** | **4.82** | **0.75** |

**Table 30: Relative Closeness to Ideal Solution**

| Criteria/ Alternative Sources | Rainwater Harvesting | Stream | Borehole | Water Tanker |
|---|---|---|---|---|
| S1 | 3.80 | 3.99 | 1.57 | 5.38 |
| S2 | 2.23 | 3.79 | 4.82 | 0.75 |
| S1 + S2 | 6.03 | 7.77 | 6.39 | 6.14 |
| $C_I$* = **S2/(S1+S2)** | **0.37** | **0.49** | **0.75** | **0.12** |

## 4.3 RANKED COMPARISON OF AHP AND TOPSIS

Comparative assessment of the ranked parameters of AHP and TOPSIS indicated congruence of results in all cases. It was observed that health impact of a proposed water supply source was given the highest priority in determining the source of water for the location. While cost was the penultimate least criteria in the AHP method, it was the least preferred in the TOPSIS method. The decision regarding the preferred source of water for Ekosodin community was borehole and followed by stream, with the last two places occupied by rainwater and water tanker supplies.

## 5.0 CONCLUSION

Multi-Criteria Analysis carried out to determine the most suitable source of water for Ekosodin community of Benin City showed that Health consideration topped the ranking as a criterion for the selection of water supply source in the location. Among the selected sources of water which included rainwater, borehole, stream and water tanker supply, borehole ranked as the preferred option of water sources. Analysis of data from a distributed questionnaires to six groups of decision make using AHP and TOPSIS methods of MCA gave an almost similar results in both methods. The consistency ratios for all the decision making groups were less than 0.1 indicating there were high level of uniformity in the opinions of the respondents in the groups. Ekosodin residents which have been experiencing low water supply for some time now will no doubt benefit immensely from these findings, considering that the best choice of water source will be selected after several options and criteria have been thoroughly examined. The study also showed that using multi-criteria analytical approach would help decision makers in making timely and accurate judgement regarding water supply issues, especially for small spatial boundaries like Ekosodin community..

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