The Use of AHP (Analytical Hierarchy Process) as Multi Criteria Decision Tool for the Selection of Best Water Supply Source for Benin City

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ABSTRACT

This paper analysis the potential of using Analytical hierarchy process (AHP) as an analytical tool in multi criteria decision analysis, to identify the best water supply source for Benin City. The water supply sources available in Benin are Rainfall, Ground Water, Surface Water and Storm Water Runoff. In order to compare characteristics and rank the four major water supply source, expert advice was solicited, structured questionnaires administered, and a set of criterions was derived that would be used in evaluation procedure. The following set of criterions was adopted: Cost, Availability, Ease of distribution, Accessibility, Sustainability, Quality. In analysing the pairwise comparative judgments in this study, Ground Water was the most important alternative as it had the highest score of 0.4130 in the computation of the weighted average, making Ground Water the best water supply source for Benin City.

Keywords: Criteria, Alternatives, Water Supply Sources, AHP, Multi Criteria

1.0. Introduction

Water is an essential life sustaining element. It pervades our lives and is deeply embedded in our cultural background (United Nations, 2006). 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 (United Nations, 2006). Selecting the best water supply source for an urban area may be understood as ultimate decision-making after systematic evaluation of appropriate alternatives is performed and related decision space is created.

The selection of the right water supply source 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, accessibility, treatment requirements, and quantity of the water in reserve; pollution propensity and the ease of distribution. 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. Multi criteria analysis helps in the processes of selecting the most suitable water source while considering the various peculiarities of a location.

The Analytic Hierarchy Process (AHP) (Saaty, 1980, 1986, 1996, 2005) appears to be a flexible decision making tool for multiple-criterion problems such as selection of the best water supply source. It enables decomposition of a problem into hierarchy and assures that both qualitative and quantitative aspects of a problem are incorporated in evaluation process. AHP has been successfully applied in case studies in water resource Engineering.

This paper intends to establish using AHP a multi criteria analysis tool to select the best water supply source for Benin City. It also examines the various alternatives available to residents and

determines 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. Material and Methods

2.1. Description of Study Area

Benin City, the capital of Edo state, is located in the south-south part of Nigeria. Figure 1 shows the map of Benin City with distribution of buildings, roads and other major infrastructures indicated.

Figure 1: Map of Benin City

There are four major water supply source in Benin City, these include:

- i. Rainfall water: This forms a good percentage of water supply source in Benin City, especially during the rainy seasons. The water is mostly collected by rainfall harvesting from roof catchment.
- ii. Surface water runoff: Benin City being in the southern part of Nigeria and close to coastal areas, have a good proportion of rivers and streams. Surface water was the main source of water supply in the 80's until the exploration of ground water and emergence of sunk boreholes.
- iii. Ground water: Benin City has an abundance of ground water which is being explored in recent times in the form of sunk boreholes.
- iv. Storm water runoff: As a result of heavy rains experience yearly, Benin City has a good proportion of storm water runoff into reservoirs which can be used as water supply source.

2.2. Methodology

To determine best water supply source in ranks, expert advice was solicited and a set of criteria was derived that would be used in evaluation procedure. The following set of criteria was adopted: Cost, Availability, Ease of distribution, Accessibility, Sustainability, Quality. AHP method was used in determining the weights for the selected criteria which was used to determine the best water supply source for the study area.

A pair wise comparison was carried out. This is achieved by comparing each criterion with the other criteria i.e. how is criterion A more important than criterion B using values from 1 to 9 see Table 1. Based on Satty's theory, a Pair-wise Comparison Matrix (weighing) is constructed: according to

Kasperczyk & Knickel (2006) and Ariff et al., (2008). Weighting coefficients for all alternatives were derived by AHP with respect to the goal which is 'Evaluating the best water supply source'. Weighing coefficients for all criteria with respect to the goal are derived using the Satty's scale after a decision has been reached on the importance of an alternative over another alternative based on expert knowledge. The pairwise comparison used the Saaty's scale of pairwise comparisons (Render and Stair, 2000).

Table 1: Satty's 9-Point Scale (Source: Alireza 2014)

Importance	Definition	Explanation
1	Equal importance	Two elements have equal importance regarding the element in higher level
3	Weak dominance	Experience or judgement slightly favours one element
5	Strong dominance	Experience or judgement strongly favours one element
7	Demonstrated dominance	Dominance of one element proved in practise
9	Absolute dominance	The highest order dominance of one element over another
2,4,6,8	Intermediate values	Compromise is needed

The procedure used for the AHP analysis was the basic AHP procedure comprising of the following steps (Moore & Weatherford, 2001);

Step 1: Developing the weights of the criteria by:

- i. Developing a single pair wise comparison matrix for the criteria;
- ii. Multiplying the values in each row together and calculating the nth root of the product;
- iii. Normalizing the aforementioned nth root of products to get the appropriate weight;
- iv. Calculating and checking the consistency Ratio (CR)

Step 2: Developing the rating for each decision alternative for each criterion by:

- i. Developing a pair wise comparison matrix for each criterion, with each matrix containing the pair-wise comparisons of the performance of decision alternative on each criterion;
- ii. Multiplying the values in each row together and calculate the nth root of the product;
- iii. Normalizing the aforementioned nth root of the product values to get the corresponding ratings;
- iv. Calculating and checking the Consistency Ratio (CR).

In real life decision problems, pairwise comparison matrices are rarely consistent. But decision makers would like to reach in the level of the consistency of the judgments, because inconsistent judgments may lead to meaningless decisions (Bozoki et. al. 2007). Saaty (1980) proposed the formula for calculating inconsistency: The equation is given as;

$$CI_n = \frac{\lambda_{max} - n}{n - 1} \quad (1)$$

Where:

CI_n Is Consistency Index,

λ_{max} Is the Eigenvalue and $\lambda_{max} > n$, and

n is the number of comparisons

Next, λ_{max} was calculated using equation (2):

$$A x = \lambda_{max} x \quad (2)$$

Where:

A is the comparison matrix of size $n \times n$, for n criteria, and

X is the Eigenvector of size $n \times 1$.

$$CR_n = \frac{CI_n}{RI_n} \quad (3)$$

CR_n is Consistency Ratio which Saaty (1980) concluded that if the value of Consistency Ratio is smaller or equal to 10%, the inconsistency is acceptable. If the Consistency Ratio is greater than 10%, we need to revise the subjective judgment, and RI_n is a Random Consistency Index, in which n is the number of comparisons.

The Random Index Table for values of n is presented in Table 2.

Table 2: Random Index Table (Source: Saaty 1980)

n	Random Index (RI)
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45

Step 3: Calculate the weighted average rating for each decision alternative so as to choose the one with the highest score.

3.0. Results and Discussion

Results obtained from expert survey and multi criteria analysis are presented below

3.1. AHP Analysis

Adopting the procedure and formula discussed in section two, using the information from water experts, we obtained our pairwise comparison matrix represented in Tables 3 – 11 for the criteria and alternatives and further calculated our consistency ratio (CR) and consistency index (CI).

The algorithm for the results presented in Tables 3 – 10 is as follows:

$$\lambda_{\max} = \Sigma (\text{SUM} \times \text{PV}) = 1.0472 + 1.0551 + 1.2032 + 0.9172 + 1.1335 + 0.9709 = \mathbf{6.3271}$$

$$\text{Consistency Index, CI} = (\lambda_{\max} - n) / (n - 1); n = 6$$

$$CI = (6.3271 - 6) / (6 - 1) = 0.3271 / 5 = \mathbf{0.06542}$$

$$CR = CI / RI; \text{ but RI for } n \text{ at } 6 = 1.24 \text{ from table 2.2}$$

$$CR = 0.06542 / 1.24 = \mathbf{0.05452}$$

Similarly, for all other pairwise comparison, this process is followed and the results presented in Tables 3 – 11.

Table 3 shows pairwise comparison of Criteria by allocating scores to each respective criterion compared with other criteria.

Table 3: AHP Pairwise Comparison Matrix of the Criteria with Respect to the Goal

Criteria	Cost	Availability	Ease of distribution	Accessibility	Sustainability	Quality	6 th root of Product	Priority Vector
Cost	1	0.143	0.5	0.25	0.143	1	0.3698	0.0476
Availability	7	1	7	1	1	1	1.9129	0.2462
Ease of distribution	2	0.143	1	0.25	0.111	0.5	0.3978	0.0512
Accessibility	4	1	4	1	1	2	1.7818	0.2293
Sustainability	7	1	9	1	1	4	2.5132	0.3235
Quality	1	1	2	0.5	0.25	1	0.7937	0.1022
SUM	22	4.2857	23.5	4	3.504	9.5	7.7692	1

As presented in Table 4, a consistency ratio (CR) of 0.05452 was obtained and is acceptable because it is less than 0.1 and therefore the judgment is consistent. This means that the decisions made by the water experts in the pairwise comparison are consistent.

Table 4: Pair-wise comparison showing Consistency Index and Consistency Ratio

Criteria	Cost	Availability	Ease of distribution	Accessibility	Sustainability	Quality	6 th root of Product	Priority Vector (PV)
Cost	1	0.143	0.5	0.25	0.143	1	0.3698	0.0476
Availability	7	1	7	1	1	1	1.9129	0.2462
Ease of distribution	2	0.143	1	0.25	0.111	0.5	0.3978	0.0512
Accessibility	4	1	4	1	1	2	1.7818	0.2293
Sustainability	7	1	9	1	1	4	2.5132	0.3235
Quality	1	1	2	0.5	0.25	1	0.7937	0.1022
SUM	22	4.2857	23.5	4	3.504	9.5	7.7692	1
SUM*PV	1.0472	1.0551	1.2032	0.9172	1.1335	0.9709	6.3271	
$\lambda_{\max}$	6.3271							
CI	0.06542							
CR	0.05452							

Table 5: Ratings for each decision alternative for each criterion

Alternatives	Rainfall	Surface Water	Ground Water	Storm Water runoff	4th root of Product	Priority Vector (PV)
Rainfall	1	5	3	5	2.9428	0.5316
Surface water	0.2	1	0.2	1	0.4472	0.0808
Ground Water	0.3333	5	1	5	1.699	0.3069
Storm Water runoff	0.2	1	0.2	1	0.4472	0.0808
SUM	1.7333	12	4.4	12	5.5362	1.0001
SUM*PV	0.9214	0.9696	1.3504	0.9696	4.2110	
$\Lambda_{\max}$	4.2110					
CI	0.0703					
CR	0.0781					

3.2. Ratings for each Decision Alternative

Pairwise comparison was carried out for each alternative using criteria adopted for this study. The ratings for each decision alternative are presented in Tables 6 – 11.

Table 6 Ratings for Availability

Alternatives	Rainfall	Surface Water	Ground Water	Storm Water runoff	4th root of Product	Priority Vector (PV)
Rainfall	1	0.2	0.1429	1	0.4112	0.0685
Surface water	5	1	0.3333	5	1.699	0.2830
Ground Water	7	3	1	7	3.4820	0.5800
Storm Water runoff	1	0.2	0.1429	1	0.4112	0.0685
SUM	14	4.4	1.6191	14	6.0034	1
SUM*PV	0.959	1.2452	0.9391	0.959	4.1023	
Λ_{max}	4.1023					
CI	0.0341					
CR	0.0379					

Table 7: Ratings for Ease of Distribution

Alternatives	Rainfall	Surface Water	Ground Water	Storm Water runoff	4th root of Product	Priority Vector (PV)
Rainfall	1	0.3333	0.3333	3	0.7598	0.1522
Surface water	3	1	0.3333	2	1.1892	0.2383
Ground Water	3	3	1	5	2.5900	0.5190
Storm Water runoff	0.3333	0.5	0.25	1	0.4518	0.0905
SUM	7.3333	4.8333	1.9166	11	4.9908	1
SUM*PV	1.1161	1.1518	0.9947	0.9955	4.2581	
Λ_{max}	4.2581					
CI	0.0860					
CR	0.0956					

Table 8: Ratings for Accessibility

Alternatives	Rainfall	Surface Water	Ground Water	Storm Water Runoff	4th root of Product	Priority Vector (PV)
Rainfall	1	2	3	5	2.3403	0.4690
Surface water	0.5	1	3	4	1.5651	0.3137
Ground Water	0.3333	0.3333	1	2	0.6866	0.1376
Storm Water runoff	0.2	0.25	0.5	1	0.3976	0.0797
SUM	2.0333	3.5833	7.5	12	4.9896	1
SUM*PV	0.9536	1.1241	1.032	0.9564	4.0661	
Λ_{max}	4.0661					
CI	0.0220					
CR	0.0244					

Table 9: Ratings for Sustainability

Alternatives	Rainfall	Surface Water	Ground Water	Storm Water runoff	4th root of Product	Priority Vector (PV)
Rainfall	1	0.2	0.2	1	0.447	0.0793
Surface water	5	1	0.5	5	1.8803	0.3339
Ground Water	5	2	1	7	2.8925	0.5137
Storm Water runoff	1	0.2	0.1429	1	0.4112	0.0730
SUM	12	3.4	1.8429	14	5.631	0.9999
SUM*PV	0.9516	1.1353	0.9467	1.022	4.0556	
Λ_{max}	4.0556					
CI	0.0185					
CR	0.0206					

Table 10: Ratings for Quality

Alternatives	Rainfall	Surface Water	Ground Water	Storm Water runoff	4th root of Product	Priority Vector (PV)
Rainfall	1	5	0.5	5	1.8803	0.3460
Surface water	0.2	1	0.2	1	0.4472	0.0823
Ground Water	2	5	1	5	2.6591	0.4894
Storm Water runoff	0.2	1	0.2	1	0.4472	0.0823
SUM	3.4	12	1.9	12	5.4338	1
SUM*PV	1.1764	0.9876	0.9299	0.9876	4.0815	
λ_{max}	4.0815					
CI	0.0272					
CR	0.0302					

Table 11: Weighted Average Rating

Criteria Alternative	Cost	Availability	Ease of distribution	Accessibility	Sustainability	Quality	Score
	0.0476	0.2462	0.0512	0.2293	0.3235	0.1022	1
Rainfall	0.5316	0.0685	0.1522	0.4690	0.0793	0.3460	0.2186
Surface water	0.0808	0.2830	0.2383	0.3137	0.3339	0.0823	0.2740
Ground water	0.3069	0.5800	0.5190	0.1376	0.5137	0.4894	0.4130
Storm runoff	0.0808	0.0685	0.0905	0.0797	0.0730	0.0823	0.0756
	1.0001	1	1	1	0.9999	1	

Table 11 shows that ground water has the highest score. Hence, ground water is chosen as the best alternative.

4.0. Conclusion

Decision-making is a complex process that requires a comprehensive evaluation of the criteria bothering the problem being assessed. The AHP has been widely accepted as a convenient decision-making tool, and this reflects in its wide use in academia and in the business community.

In this study, the AHP methodology was employed to select the best water supply source for Benin City.

The criteria considered in making the decision included Cost, Availability, Ease of distribution, Accessibility, Sustainability and Quality while the alternatives considered were Rainfall, Ground Water, Surface Water and Storm Water Runoff. In analysing the pairwise comparative judgments in this study,

Cost was found to be the most important criteria and Ground Water, the most important alternative as it had the highest score in the computation of the weighted average.

Despite the strengths of the AHP, it comes with some observed weaknesses. The problem of inconsistency in the judgment was observed. This often resulted in situations where we had to re-evaluate our responses to questions raised in order to satisfy the acceptable inconsistency limit.

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