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ORIGINAL ARTICLE

Evaluation of management alternatives for urban water supply system using Multicriteria Decision Analysis

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Stakeholder preference modeling;
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Abstract The Analytic Hierarchy Process (AHP) was used to study the urban water supply scheme for Offa, in Kwara State, Nigeria. The Offa water works is studied with the model so as to assist its future operation and the design of alternative system improvement works. AHP, a technique used in Multicriteria Decision Analysis (MCDA) had made important contribution to the practical decision making process by recognizing the decision makers (DMs) experience and in providing the possible best compromised solution in terms of multiple objectives and multiples DMs and stakeholders preferences. The study introduces three management options that are formulated on the prevailing nation's water supply sector and foreign countries models. The three options are respectively: Public Ownership and Operation; Public Ownership and Private Operation; and Private Ownership and Operation. The stakeholders have chosen option 1 (Public Ownership and Operation) as most contributing to sustainable operation of an urban water supply service delivery under scrutiny of environmental, economical, technical, institutional, and socio-cultural criteria. The choice of option 1 reaffirms the stakeholder opinion in the survey that they did not want government to abandon their responsibility in the water sector. The ranking of the choice is based on the compromise solutions according to the performance of the system under various alternatives that are considered and the preference of the decision makers (DMs) or stakeholders on Performance Indicators or Measures (PIs or PMs). Subsequently, the AHP framework is more valuable and effective in facilitating an explorative insight into the problem.

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1. Introduction

The task of providing water to urban citizens has remained daunting for decades. Water supply delivery management involves many factors, qualitative and quantitative, tangible and intangibles, and includes many interest groups and stakeholders. Subsequently, it is not easy to solve water problems that satisfy all groups. All problems associated with sustainable urban water supplies are wicked ones which Yoe (2002) describes as having no right answer. Wicked problems are found at the intersection of science and values. The problem

of uncertainty is embedded in all wicked problems along with the problem of human rationality (Khisty and Mohammadi, 2001). Any solution to wicked problem is only better or worse. In the face of wicked problems, it is therefore unrealistic to look for optimal solution because it rarely exists. Rather it is essential to be able to find compromise solutions. The Multi-criteria Decision Analysis (MCDA) is a holistic approach to solving wicked problem. It is a general forum within which several variables and models can be combined to incorporate all necessary interacting components in the decision making process (Al-Zu'bi and Al-Kharabsheh, 2003).

2. Multicriteria Decision Analysis (MCDA)

The philosophical bases of multicriteria approach are to provide insight into the nature of the conflicts among objectives and reach consensus among stakeholders rather than eliminating the conflicts (Kheireldin and Fahmy, 2001). However, MCDA methods differ in the way the idea of multiple criteria is considered, the application and computation of weights, the mathematical algorithm utilized, the model to describe the system of preferences of the individual facing decision making, the level of uncertainty embedded in the data set and the abil-

ity for stakeholders to participate in the process (Pietersen, 2006). There are many different concepts and methods for MCDA. Some of the potentially useful techniques are goal programming, compromise programming, multiattribute utility theory (MAUT), analytical hierarchy process (AHP), ELECTRE I-III, PROMETRE, and co-operative game theory.

AHP is a MCDA methodology that allows objective as well as subjective factors to be considered in a decision making process. Like other MCDA techniques, its purpose is to develop a theory and provide a methodology for modeling unstructured decision choice problems. Basically, AHP helps to determine which variable has the highest priority and should be acted upon to influence the decision outcome. AHP relies on the supposition that humans are capable of making relative judgments than absolute judgments; and it is based on the key principles of decomposition, comparative judgement, and synthesis of priorities (Dey, 2003). There are many ways of including the views and judgement of each person in the priority setting process. In a common objectives context, there are four ways to set priorities: (1) consensus, (2) vote or compromise, (3) geometric mean of the individuals' judgement, and (4) separate models or players. AHP has been found to be an effective

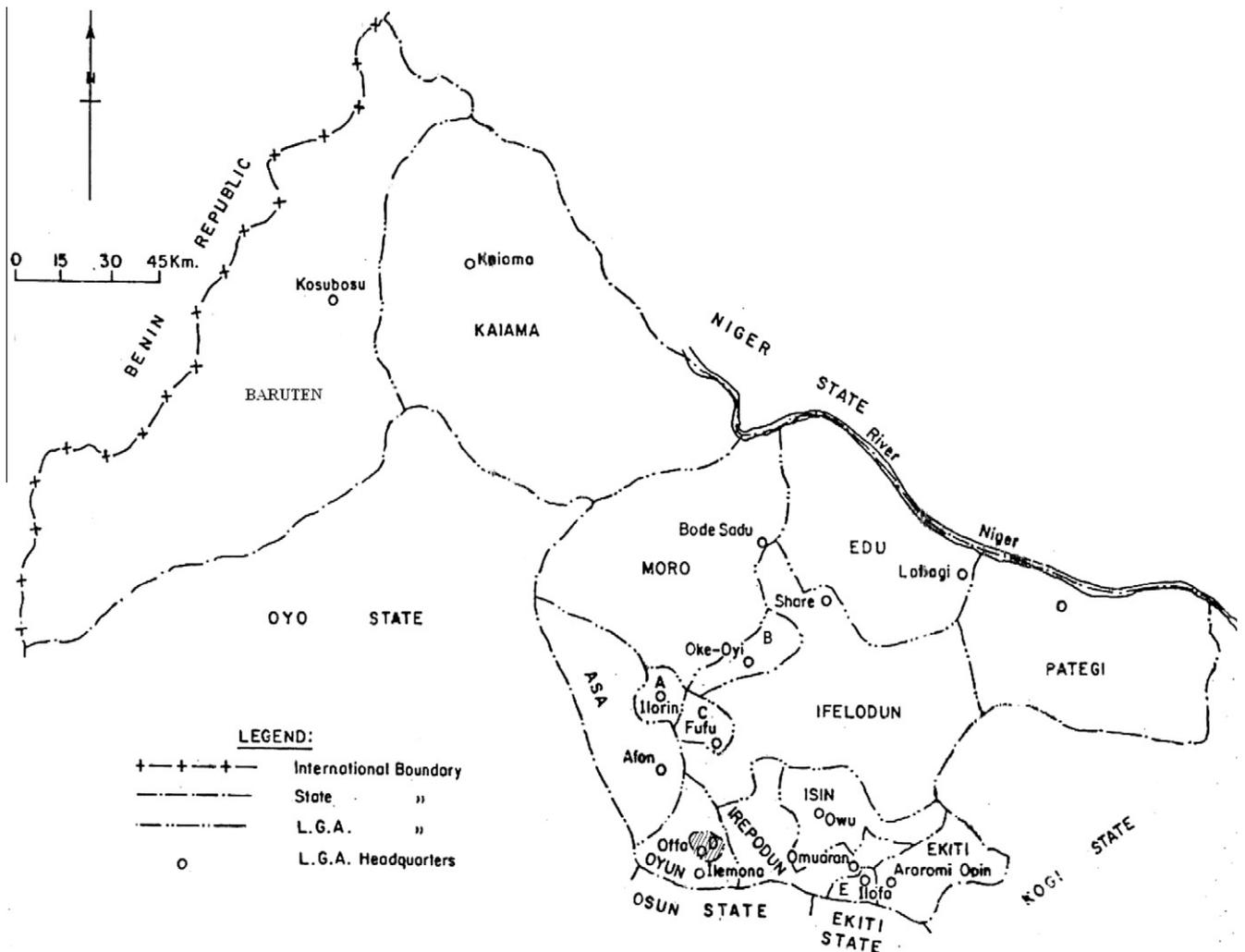


Figure 1 Map of Kwara State local government areas (study area is hatched).

Table 1 The pairwise comparison scale.

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance	Experience and judgment slightly favor one activity over another activity over another
5	Strong importance	Experience and judgment strongly favor one
7	Very strong importance	An activity is favoured very strongly over another; its dominance demonstrated in practice.
9	Extremely importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, and 8	Intermediate values between adjacent scale values	Compromise is needed between two judgement

Source: Saaty (2000).

methodology to obtain group consensus in a highly political environment. Its usage is also because a good decision support system (DSS) must be able to cope with poor data, allow integration of human judgement in the process and create enough discrimination between motivations to make result significant.

Jaber and Mohsen (2001) employ the use of AHP to develop a decision support system for the evaluation and selection of potential non-convectional water resources supply in Jordan. The criteria under which multicriteria analysis were performed were economic, technical, availability, reliability, and environmental sustainability. It was concluded that water desalination was the most promising resource, followed by water harvesting. AHP has been used to analyze the competing national claims to water from the Euphrates River by Turkey, Syria, and Iraq. It has also been used at sub-national regional scale to assess stakeholder preferences in developing aquifer demand policies to manage the Ogallala Aquifer in the central USA (Al-Zu'bi et al., 2002). The Analytic Hierarchy Process (AHP) is adopted in this study to model multiobjectives management strategies for an urban water supply. The AHP was used to study the urban water supply scheme for Offa, the headquarters of Offa LGA of Kwara State, Nigeria. (Fig. 1). The Offa water works is studied with the model so as to assist its future operation and the design of alternative system improvement works.

3. Methodology

A general form of a hierarchical model of a decision problem is a hierarchy with broad overall objective (or goal) at the highest level. The lower levels list the criteria and respective subcriteria used to choose among alternatives. At the lowest level are the alternatives to be evaluated. As a consequence of this methodological structure, respondent in an AHP survey are less likely to adopt mental short cuts by concentrating disproportionately on one criteria or level. Thus AHP can deliver enough discrimination between motivations to make results significant. A set of comparison matrices of all elements in a level of the hierarchy with respect to the immediate higher level are constructed. This is aimed to prioritize and convert individual comparative judgements into a ratio scale of measurements using Saaty's nine-point scale (Table 1). It is important to note that the values selected from the Saaty scale represent linguistic, and somewhat fuzzy, responses and do not represent strict algebraic ratios. This allows incorporation of qualitative and

Table 2 Hypothetical DMG.

1. Federal ministry of water resources
2. State ministry of water resources and rural development
3. State water agencies
4. Water industry consultants
5. Financial institutions (banks)
6. Consumers

subjective information into the analysis (Palmer and Lund, 1985).

The AHP model for this study comprises of hierarchies that define: (1) the driving goal; (2) the objectives to achieve the goal; (3) further objectives to evaluate the objectives; and (4) the alternative decision choices to meet the goal. A group decision making process through organized workshop is required in the formulation of the objectives (criteria) and alternatives strategies to evaluate and synthesize these objectives. However, due to logistics and limited fund this could not be organized. The study then considered a hypothetical Decision Making Group (DMG) with representation from the important stakeholder groups identified in Table 2. This is accomplished through indirect preference elicitation using questionnaire survey. The information extracted was used to model the experts and stakeholder preference.

Three alternatives strategies or options for the AHP assessment were identified. Table 3 shows the basic characteristic of the three alternatives or options (Bakker, 2006; Hukka and Katko, 2003; World Bank, 1994). The policies considered are synthesized from general policies on water for the nation based on many reports and documents (e.g., FMWR, LNRB, JICA, etc.). In addition, personal interactions were made with individuals among the groups in Table 2 most especially in state water agency, water industry consultants, and consumers. The knowledge, experience or interaction of different components of water supply delivery system also aided in identification of sustainability factors/objectives for evaluation of the goal.

The sets of the objectives have been so determined to cater for all major concerns on sustainable service delivery of an urban water supply. As such a total of 19 Performance Indicators (PIs) that summarize the performance of the sustainability of system objectives were identified and are listed in Table 4. These were used to evaluate the individual alternative strategy

Table 3 Characteristics of institutional/management options.

Option 1: Public Ownership and Operation

- Fully public management of water supply through government agency or organ
- This arrangement need not result in inefficient operation and suboptimal level of service, but it has often be
- Difficulty of securing timely financing for investment
- System encourages asset stripping due to overdependence on budgetary allocation
- There exist multiple objectives without effective tradeoff approach and thus complicate the managerial ability to deliver satisfactory level of service
- Corporatization has not been effective even in improving collection ratio due to lack of effective competition as well as politization of organizational and managerial structure

Option 2: Public Ownership and Private Operation

- Ownership of asset belong to the government
- Unbounding noncore activities (operations & services) for competition
- Outsourcing of noncore activities through various contractual arrangement within the context of public private participation concept but short of full privatization
- Preserve the basic responsibility of government
- Competition in noncore activities results in technically efficient and financially viable operation
- Strong autonomous regulatory body is crucial to ensure safeguarding of externalities in water service delivery

Option 3: Private Ownership and Operation

- This is full privatization
- Autonomous private company assumes full responsibility for water supply service provision
- The company takes over the former public body asset and liabilities
- Concentration of market power
- High risk of monopoly abuse
- Effective judicial and regulatory system is crucial to capture externalities concern

Table 4 Objectives and related performance measures (PMs).

Environmental (Water Resource)	1. Withdrawal 2. Quality 3. Reliability 4. Vulnerability
Economic	1. Financial viability 2. Economic of scale 3. Securing of investment resources 4. Minimization of production cost
Technical (Infrastructures)	1. Access to advance technology 2. Expertise employee 3. Operational efficiency
Institutional	1. Legal framework 2. Policies 3. Regulatory control 4. Participation
Socio-cultural	1. Public health and safety 2. Accessibility 3. Coverage 4. Intergenerational equity

contribution to an overall goal. In identifying the vehicle by which the goal is accomplished, five useful instruments were considered for implementation of formulated alternative strategies. The instruments were:

1. Direct government intervention (Funding)
2. Institutional and organizational arrangements
3. Economic and market based instruments
4. Regulatory instruments
5. Socio-cultural instruments

4. Analysis and discussion of results

The administered questionnaires were for the purpose of eliciting preference information from stakeholder groups. Based on identified sustainability factors, the model hierarchy structures are formed as shown in Fig. 2. The model hierarchy is composed of four levels. The first level defines the goal to be achieved which is to select the suitable management strategy for sustainable operation of an urban water supply system. The second level outlines the main objectives to be synthesized to achieve the goal. These are sustainability factors for the stated goal. The third level contains the sub-objectives which are basically the PIs for the evaluation of lower level of the hierarchy. The fourth level list the institutional/management options considered suitable for the problem.

Pairwise comparisons were carried out on the components of the hierarchy structures in Fig. 2 from upper level to lower levels. The calibration of pairwise comparison was carried out to ensure consistency of judgement. The geometric mean of each element of the pairwise comparison matrix of individuals is estimated as the group judgement or consensus. The group judgement of N decision makers is (Karamouz et al., 2003):

$$a_{ij} = (a_{ij}^1 \times a_{ij}^2 \times \dots \times a_{ij}^N)^{1/N} \tag{1}$$

where N is the number of decision makers, and a_{ij} is the group judgement of relative importance of indicator i compared with the indicator j (ij th element of pairwise decision matrix). The pairwise comparison values of the objective relative to the main goal are transformed into a normalized matrix to obtain their respective relative weights are shown in Table 5. All the alternative management options were compared with each other relative to each of the objective to establish respective relative weights of their priorities. Table 6 shows the relational scoring and relative weights for the different institutional/

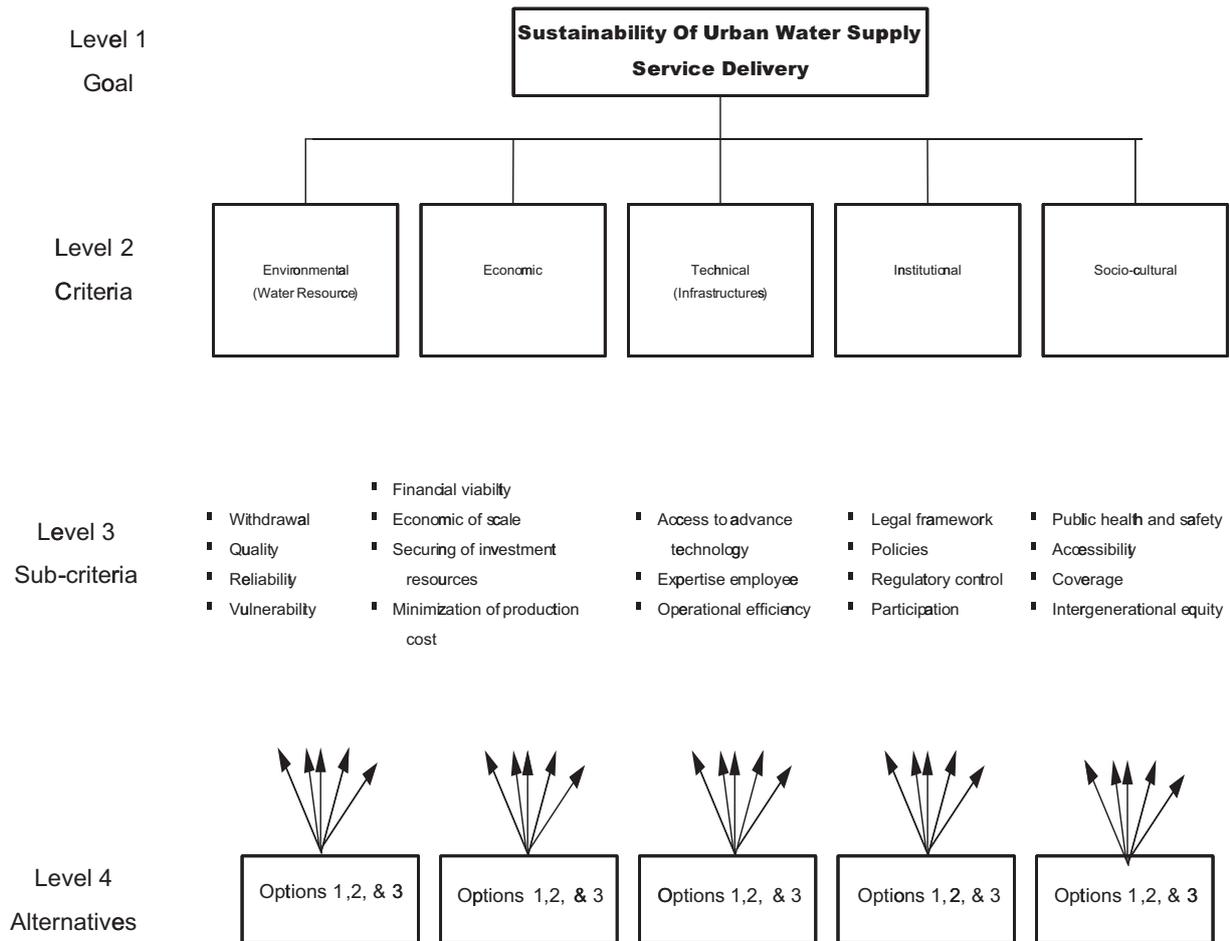


Figure 2 The generic AHP model for sustainability of urban water supply service delivery.

Table 5 Pairwise comparison of objectives.

Criteria	Environmental	Economic	Technical	Institutional	Socio-cultural	Relative weights
Environmental	1.00	2.00	2.00	2.00	2.00	0.32
Economic	0.50	1.00	2.00	2.00	2.00	0.24
Technical	0.50	0.50	1.00	2.00	2.00	0.19
Institutional	0.50	0.50	0.50	1.00	2.00	0.14
Socio-cultural	0.50	0.50	0.50	0.50	1.00	0.11

management options considered, relative to individual criterion. From the results in Tables 5 and 6, the global relative weights (Table 7) were generated for the three management options considered by calculating their eigenvalues as (Hongre, 2006):

$$w^k u = \lambda u \tag{2}$$

where u is a $1 \times n$ vector, λ is an unknown scalar to be determined. Solving the eigenvalue problem leads to a set of eigenvalues (each being associated to a specific eigenvector). Then the largest eigenvalue λ_{max} is considered and its associated eigenvector w^k_{max} .

Fig. 3 shows the generated relative global weights for the three management options considered for sustainable for urban water supply service delivery. The analyses of the three

management options revealed that option 1 was the most favoured under environmental, economical, technical, institutional, and socio-cultural criteria. It was followed by option 2 while option 3 took the distant third. The choice of option 1 reaffirms the stakeholders opinions in the survey that the government at various levels should continue to play major roles in public water supply.

5. Conclusion

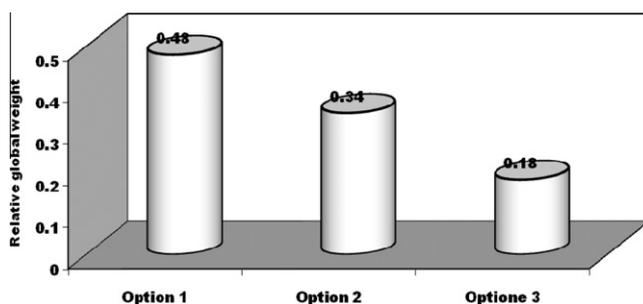
The AHP of MCDA techniques had made important contribution to the practical decision making process by recognizing the DMs experience and in providing the possible best compromised solution in terms of multiple objectives and multiples DMs and stakeholders preferences. For the Offa urban water

Table 6 Pairwise comparison of management options.

Criteria	Option 1	Option 2	Option 3	Relative weights
<i>Environmental</i>				
Option 1	1.00	2.00	2.00	0.48
Option 2	0.50	1.00	3.00	0.35
Option 3	0.50	0.33	1.00	0.17
<i>Economical</i>				
Option 1	1.00	2.00	2.00	0.48
Option 2	0.50	1.00	3.00	0.35
Option 3	0.50	0.33	1.00	0.17
<i>Technical</i>				
Option 1	1.00	2.00	2.00	0.48
Option 2	0.50	1.00	3.00	0.35
Option 3	0.50	0.33	1.00	0.17
<i>Institutional</i>				
Option 1	1.00	2.00	2.00	0.49
Option 2	0.50	1.00	2.00	0.31
Option 3	0.50	0.50	1.00	0.20
<i>Socio-cultural</i>				
Option 1	1.00	2.00	2.00	0.49
Option 2	0.50	1.00	2.00	0.31
Option 3	0.50	0.50	1.00	0.20

Table 7 Optimum management alternatives.

Criteria	Overall relative weights		
	Option 1	Option 2	Option 3
Environmental (0.31)	0.48	0.35	0.17
Economical (0.24)	0.48	0.35	0.17
Technical (0.22)	0.48	0.35	0.17
Institutional (0.13)	0.49	0.31	0.20
Socio-cultural (0.10)	0.49	0.31	0.20
Relative weights	0.48	0.34	0.18

**Figure 3** Relative global weights for the three management options.

scheme in Kwara State, Nigeria, the stakeholders preferred option 1, since it will contribute highly to sustainable water supply service delivery while satisfying environmental, economical, technical, institutional, and socio-cultural criteria.

Hukka and Katko (2003) separated the responsibilities for ensuring adequate services are provided from the task of

actually producing services. What is fundamental is in the allocation of ownership, financing, operation, and risk responsibilities. The stakeholders view is that for the urban water supply service delivery to be sustainable on the long term, the following are needed:

- it must be financially sustainable at operation and maintenance level and;
- the dual role of the government as the producer and regulator should be abandoned.

The ranking of the choice is based on the compromise solutions according to the performance of the system under various alternatives that are considered and the preference of the DMs or stakeholders on PIs or PMs. Subsequently, the AHP framework is more valuable and effective in facilitating an explorative insight into the problem. The DMs are now better informed to make the final choice of decision.

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