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# Multi-Criteria AHP Approach for the Optimal Selection of Sites for Transport and Water Storage: A Comparative Analysis

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**Abstract.** In decision-making issues involving a strong spatial dimension, such as the search for the optimal position for an arrangement, decision-makers must face a multitude of information, performance indicators, and the requirements of sustainable development. Often, the choices made reflect more trade-offs between technical constraints and financial budgets than environmental priorities. To overcome this limitation, we propose an approach combining Geographic Information Systems and multi-criteria analysis. The Analytic Hierarchy Process method is particularly effective for prioritizing sites based on multiple and sometimes conflicting criteria. Considering six criteria (social, environmental, and economic), we demonstrate the relevance of this approach through an applied illustration, thus offering a robust decision aid for the selection of optimal sites.

**Keywords:** Analytic Hierarchy Process, Geographic Information System, Multicriteria Analysis, Sustainable Development.

## 1. INTRODUCTION

Water resource management is a major challenge in many parts of the world, especially in areas subject to environmental and economic constraints. The issue of global warming challenges years of urban planning practices, and encourages the use of new alternative methods to solve urban ills and reduce vulnerability. Structural approaches to managing risks through hazard control have shown their limitations. Since the beginning of the 20th century, many international studies have made it possible to test and implement new practices, so-called alternatives to conventional systems. They are known by various names such as “Best Management Practices (BMP)”, Low Impact Development (LID) Practices” or “Sustainable Urban Drainage System (SUDS)” , and “Alternative Techniques” or “Optimal Management Practices” (PGO) of stormwater and converge towards a common objective of simulating “hydrological conditions prior to the development of the territory” . The Optimal Stormwater Management Practices seek to slow the phenomenon of runoff to relieve these unitary networks, by creating structures that promote evaporation, natural infiltration or temporary storage of stormwater volumes. Urban management of rain is evolving towards solutions closer to the territory. Technicians refer to ”compensatory techniques 1 to urbanization” [3]. However, the main difficulty arises primarily from the choice of site location, as poorly coordinated developments can lead to simply moving flooding from one location to another. Then, when choosing the best location for a sewage plant construction, is immediate: economic and space constraints do not allow managers to invest massively in infrastructures that could simultaneously meet these two objectives: the minimization of olfactive nuisances by distance from the cost of housing and water supply. Finally, to counter overflows and limit pollution from urban runoff, the choice of sites and works is in perpetual conflict. The construction of water transport and storage facilities is a strategic solution to meet these needs, but it requires complex decision-making. This complexity is linked to the need to integrate several often conflicting criteria, such as environmental impacts, economic costs and social issues. So, it is necessary to make the choice of sites and works that will reflect an arbitrage between the available technical means, financial means and environmental convictions of communities, or even their real desire to protect natural environments. In other words, the site chosen must have a wealth of components (multifunctionality, diversity of landscape, equipment, educational value) and is similar to a neighborhood park, located near a residential area. The choice of a sewage disposal and treatment system and its components should be based primarily on local characteristics relating to natural soil potential, available area and slope. Decisionmakers seek to maximize or minimize each criterion considered. They are confronted, on the one hand, with a considerable mass of information on performance indicators and, on the other hand, with the transition from qualitative to quantitative value. As a result, it is sometimes difficult to design basins that play an optimal role both for the limitation of pollutant spills and for the limitation of overflows. This double problem makes the basin development program more complex and expensive. This led him to think and develop a methodology that would allow the best assessment of exclusive criteria and assessment in order to choose an optimal site for the Water Transport and Storage Works. The objective of this article is to present a multicriteria approach based on the Analytic Hierarchy Process (AHP) to optimize the selection of sites. We propose a comparative analysis to assess the robustness of results using AHP compared to the ORESTE and PROMETHEE methods when preferences for criteria are not well-explained


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## 2. ISSUES AND CHALLENGES

Land use planning combines and reconciles several very distinct disciplines: architecture, engineering, biology, law, economics, geography, history, sociology, etc. The developer must comply with the principle that all interests in play must be weighed and their. possible effects taken into account. In many decision-making problems where the spatial dimension is important and particularly in the problem of finding the optimal position for a development, The Planning Authority is confronted with a set of criteria providing a reference system to assess the ability of a place to meet one or more objectives, but not allowing it to reach the level of technical requirements intended a priori. It follows that instead of finding the optimal position for a development, it may find the position which is certainly the reflection of an arbitrage between the available technical means and the financial means but not the environmental convictions of the communities. In the context of water resource management, the selection of sites for transport and storage infrastructure must meet a variety of criteria:

- Environmental: minimization of impact on ecosystems;
- Cost effective: reduced construction and operating costs;
- Social: local acceptance and accessibility of infrastructure.

However, these criteria are often conflicting and difficult to quantify. Therefore, a robust and transparent methodology is needed to support decision-making.

## 3. METHODOLOGY: ANALYTIC HIERARCHY PROCESS (AHP)

AHP is a multi-criteria analysis method that allows alternatives to be prioritized according to weighted criteria. It is carried out in three main stages:

(i) Hierarchical breakdown: structuring the problem into a hierarchical model including overall objective, criteria and alternatives;

(ii) Peer comparisons: evaluation of criteria and alternatives in relative terms according to a priority scale;

(iii) Overall Priority Calculation: Determination of a final ranking based on assigned weights and scores.

The AHP method is a decision support method that is characterized by its ability to determine the weights of criteria.

### 3.1. Hierarchical breakdown

Identification of the analysis and objective of the project: The objective may be, in reference to a goal, an outcome to be achieved, the point where one proposes to achieve, what one aims at.

Development of project reporting structure: The hierarchical structure of the project reflects the issue to be resolved. For this, you need to define a hierarchical tree of criteria and sub-criteria. Clarifies the problem and allows us to identify the contribution of each element to the final decision. The structure is as follows: the objective of the problem at level 1 in the hierarchy, the criteria at level 2, the subcriteria at level 3, and the alternative at the last level in the hierarchy.

### 3.2. Peer comparisons

Performing the pair comparison: After the hierarchical structure of the problem, the pair comparison is performed by each branch of each level. For each comparison, the most important criterion must be chosen and its importance judged. To measure the relative importance of each criterion in relation to others, we use the judgment scale developed by Saaty.

**Table 1:** Saaty scale.

| Verbal judgment | Extremely more important | Very much more important | Significantly more important | Moderately more important | Equal importance |
|---|---|---|---|---|---|
| Numerical | 9 | 7 | 5 | 3 | 1 |

The values 2,4,6,8 are intermediate values of judgements.

Establishment of the comparison judgment matrix: The comparison results in the design of a judgment matrix which is a matrix of order n where n is the number of criteria of each branch in each level. The matrix is as follows :

$$A = \left[\, a_{ij} \right] = \begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{pmatrix} \tag{1}$$

With $a_{ii} = 1$ and $a_{ji} = \frac{1}{a_{ij}}$ what gives us a matrix $A = \left[\, a_{ij} \right] = \begin{pmatrix} 1 & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ \frac{1}{a_{1n}} & \cdots & 1 \end{pmatrix}$

### 3.3. Overall Priority Calculation

Calculation of priority vector This step consists of calculating the relative importance of each of the elements at each hierarchical level all having a link with the previous level from the evaluations made in the previous step. For this, the matrix A obtained in the previous step is normalized by column to obtain a matrix B with $B = [b_{ij}] = \begin{pmatrix} \frac{1}{\sum_{i=1}^{n} a_{i1}} & \cdots & \frac{a_{1n}}{\sum_{i=1}^{n} a_{in}} \\ \vdots & \ddots & \vdots \\ \frac{a_{n1}}{\sum_{i=1}^{n} a_{i1}} & \cdots & \frac{1}{\sum_{i=1}^{n} a_{in}} \end{pmatrix}$. (2)

Calculation of criteria weight To calculate the weight of criteria or sub-criteria, we calculate the C matrix whose coefficients are defined by

$$C = \left[ c_{ij} = \frac{b_{ij}}{\sum_{i=1}^{n} b_{ij}} \right]. \quad (3)$$

Each line corresponding to a criterion, the average associated with the criterion defines the weight of the criterion or sub-criterion. The weights $w_i$ are obtained by the following relation $w_i = \frac{1}{n}\sum_{j=1}^{n} c_{ij}$ where i indicates the i-th criterion of the group, we have the following relationship $\sum_{i=1}^{n} w_i = 1$. At each hierarchical level and by group of criteria or sub-criteria having the same link with previous level, the value $\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n} \lambda_i$ is calculated where $\lambda_i = \frac{1}{w_i}\sum_{j=1}^{n} a_{ij} w_j$.

Calculation of the Coherence Index (CI) If his or her assessment is acceptable, $\lambda_{max}$ must remain close to n. Thus $\lambda_{max} - n$ measures well the consistency of the answers to questions asked to the main decision makers. The conherence index (CI) is obtained by

$$CI = \frac{\lambda_{max} - n}{\sum_{i=1}^{n} b_{ij}}. \quad (4)$$

The coherence index (CI) measures the reliability of the comparison expressed to consistent judgements.

Determination of the Random Index (RI) value The Random index (RI) represents the average of the indices calculated at each replication for different square matrix size order n. T.L. Saaty[2] developed a scale where the random indices were established. The following table represents the Random Indices where n represents the number of criteria or subcriteria.

**Table 2:** Random Indices.

| **n** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
|---|---|---|---|---|---|---|---|---|---|---|
| Random Index (RI) | 0 | 0 | 0.52 | 0.89 | 1.11 | 1.25 | 1.35 | 1.40 | 1.45 | 1.49 |

Calculation of the Consistency Ratio (CR) The Coherence Ratio (CR) is the ratio of the coherence index calculated on the matrix corresponding to the decision-makers and the Random Index (RI) of a matrix of the same dimension. $CR = \frac{CI}{RI}$.

CR measures the logical consistency of expert judgements. It allows to evaluate the consistency of judgements by the method of comparison in pairs. It provides information on the consistency in terms of ordinal and cardinal importance of the criteria to be compared.

The Coherence Ratio (CR) can be interpreted as the probability that the matrix is completed randomly[3]. Saaty suggests a threshold of 10% for this consistency index [2] ie if $CR \leq 0.1$ or 10% then the judgements of assessment of the criteria were consistent.

Aggregation of alternatives Once the judgements are consistent at all levels, then the weights of the sub-criteria in the final assessment are obtained by multiplying the weight of each sub-criterion by the weight of the corresponding criterion. These final weights are used to aggregate the performance of alternatives. These aggregations allow the alternatives to be classified from the best performing to the worst performing or vice versa.

## 4. CASE STUDY: SITE SELECTION IN BURKINA FASO

### 4.1. Context

Burkina Faso, with its semi-arid climate, faces increasing challenges in water management. Strategic construction in priority areas is essential to meet the growing demand for water.

### 4.2. Criteria Considered

For this study, six main sub-criteria were selected, grouped into two criteria:

(i) Hydrographic factor $C_1$: $C_{1j}, j = 1,2,3$ refer to the sub-criteria Slopes, Support Soil and Proximity to the River System respectively ;

(ii) Social factor $C_2$: $C_{2j}, j = 1,2,3$ refer respectively to the sub-criteria, proximity to residential areas, proximity to the road network and occupied area.

### 4.3. Data and Tools

We have considered the data from Yougbar´e and Datalouboye [4]. The authors took into account the exclusion criteria applied to 187 sites originally proposed, and retained only 6 sites that met the conditions. We used the AHP method as described in previous sections to determine the weight of criteria in order to avoid subjective weighting of criteria weights. These weights were then used to aggregate the weights in order to evaluate the overall performance of the sites. We will note $S_1 \ldots, S_6,$ for the six sites. The analysis was performed using an implementation software of Excel 2016.

By normalizing the data on the assessed performance of sites against the six assessment criteria, the table 3 summarizes the values obtained.

**Table 3:** Site performance matrix.

| | $C_{11}$ | $C_{12}$ | $C_{13}$ | $C_{21}$ | $C_{22}$ | $C_{23}$ |
|---|---|---|---|---|---|---|
| Site 1 | 78 | 60 | 40 | 10 | 10 | 27 |
| Site 2 | 100 | 40 | 80 | 58 | 38 | 48 |
| Site 3 | 33 | 80 | 20 | 10 | 42 | 85 |
| Site 4 | 10 | 80 | 100 | 10 | 100 | 99 |
| Site 5 | 78 | 100 | 40 | 45 | 22 | 90 |
| Site 6 | 78 | 100 | 80 | 100 | 35 | 63 |

## 5. RESULTS AND DISCUSSION

### 5.1. Ranking of Sites

The application of the methodology generated a ranking of sites according to their overall suitability. The best ranked sites have an optimal balance of criteria.

#### 5.1.1. Weight

Applying AHP results in the weights of the criteria at hierarchical level 2. These weights are given by the Table 4.

**Table 4:** Criteria Judgment Matrix.

| | $C_1$ | $C_2$ | Weight |
|---|---|---|---|
| $C_1$ | 1 | 5 | 83.33% |
| $C_2$ | $\frac{1}{5}$ | 1 | 16.67% |
| $\lambda_{max} = 2, CI = 0, CR = 0\%$ | | | |

CR = 0% ≤ 10%, then the comparison consistency index is acceptable.

Applying AHP gives the weights of the sub-criteria of hierarchical level 3 of criterion $C_1$. These weights are given by the Table 5.

**Table 5:** Subcriteria Judgment Matrix for Hydrographic Factors.

| | $C_{11}$ | $C_{12}$ | $C_{13}$ | Weight |
|---|---|---|---|---|
| $C_{11}$ | 1 | 7 | 5 | 72.35% |
| $C_{12}$ | $\frac{1}{7}$ | 1 | $\frac{1}{3}$ | 8.33% |
| $C_{13}$ | $\frac{1}{5}$ | 3 | 1 | 19.31% |
| $\lambda_{max} = 3.0657, CI = 0.0328, CR = 5.6\%$ | | | | |

CR = 5.6% ≤ 10%, then the comparison consistency index is acceptable.

Applying AHP gives the weights of the sub-criteria of hierarchical level 3 of criterion $C_2$. These weights are given by the Table 6.

**Table 6:** Subcriteria Judgment Matrix for Social Factors.

| | $C_{11}$ | $C_{12}$ | $C_{13}$ | Weight |
|---|---|---|---|---|
| $C_{11}$ | 1 | 5 | $\frac{1}{3}$ | 28.28% |
| $C_{12}$ | $\frac{1}{5}$ | 1 | $\frac{1}{7}$ | 7.37% |
| $C_{13}$ | 3 | 7 | 1 | 64.33% |
| $\lambda_{max} = 3.0654, CI = 0.0327, CR = 5.6\%$ | | | | |

CR = 5.6% ≤ 10%, then the comparison consistency index is acceptable.

Applying AHP results in the weights of the sub-criteria combined with the weights of the corresponding top level. These weights are given by the table 7.

**Table 7:** Final weights of sub-criteria.

| Sub-criteria | $C_{11}$ | $C_{12}$ | $C_{13}$ | $C_{21}$ | $C_{22}$ | $C_{23}$ |
|---|---|---|---|---|---|---|
| Weight | 60.29% | 6.94% | 16.09% | 4.71% | 12.20% | 10.72% |

### 5.1.2. Final Site Performance Scores

Once the weights are obtained, the aggregation principle is applied to obtain the site performance scores (Table 8). These scores reflect the order of importance of the overall decision preference function.

**Table 8:** Site performance with AHP

| Site | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | $S_6$ |
|---|---|---|---|---|---|---|
| Score | 61 | 84 | 39 | 40 | 72 | 79 |

The results show the following ranking:

$$S_2 \succ S_6 \approx S_5 \succ S_1 \succ S_4 \succ S_3$$

Where $a \succ b$ means that the information used allows to accept, that the site a is preferable to the site b and $c \approx d$ means that the information used allows to accept, that there is an indifference to choose the site c or the site d.

## 5.2. Comparative Analysis

A comparison of the AHP approach with other methods (such as ORESTE [5] or PROMETHEE [6, 1] has shown that the AHP provides greater transparency in weighting criteria and better understanding of trade-offs.

In [4], criteria were ranked at each hierarchical level by ranking them according to importance. It is clear from this work that the following classification in descending order of importance.

$$S_6 \succ S_5 \succ S_4 \succ S_2 \succ S_3 \succ S_1$$

The two results show a different order. This difference is mainly due to the fact that in the work [4] the judgements regarding the criteria between them are not well supplied. Weights were not explicitly calculated by the ORESTE method. This limit is filled by the AHP method. The PROMETHEE method needs weight for its application. These results show that it is necessary to go through steps to obtain well-defined weights before applying

certain methods such as ORESTE and PROMETHEE. Indeed, with this example of case study, we note that the ranking obtained in [4] rank S2 in fourth position while in the present study S2 is the most efficient in view of the information. In this work, we have sought to better understand the decision-maker's judgments by seeking precise answers of judgements by pair of criteria. For example, there is a strong preference between the first criterion ($C_{11}$) with a weight of 84% and the other criteria. Site 2 is better than other sites in relation to this criterion which makes it more efficient overall.

## 6. CONCLUSION AND PERSPECTIVES

This study highlights the usefulness of AHP for the selection of sites for water works, taking into account multiple and often conflicting criteria. The approach presented provides a robust and adaptable decision support framework, which informs policy choices while addressing sustainability issues. The results obtained offer promising prospects for improving planning processes in similar contexts. The main limitations identified are the

subjectivity of the weights and the reliance on quality data. Perspectives include the integration of hybrid methods (AHP-SIG) and validation of results by field experts. It would also be interesting to include certain criteria such as: Proximity to water sources, The cost of construction, Environmental impact, Accessibility of infrastructure, Social acceptability, The risks related to climatic hazards.

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