Journal of Engineering and Sustainable Development
Vol. 29, No. 01, January 2025
https://jeasd.uomustansiriyah.edu.iq/index.php/jeasd
ISSN 2520-0917
Research Article
https://doi.org/10.31272/jeasd.2795

Decision Support System for Proper Utilization and Management of Water Resources in Egypt

Yara A. Zaki[1*], Yasser El-Elsaie[1], Ibrahim M. Mahdi[2], Mohamed. M. Ibrahim[3]

[1]Civil Engineering Department, Higher Institute of Engineering at El-Shorouk City, El Shorouk Academy, Cairo, Egypt
[2]Structural Engineering Department, Faculty of Engineering, Future University in Egypt
[3]Civil Engineering Department, Faculty of Engineering at Shoubra, Benha University, Cairo, Egypt

[*]Email: y.zaki@sha.edu.eg.

Article Info

Received 18/06/2024
Revised 28/11/2024
Accepted 10/12/2024

Abstract

The decision-making theory has become essential for providing real-time solutions to uncertainty problems, particularly in sustainable engineering and environmental challenges in engineering processes. This work uses decision-making techniques to address water resource problems using the Analytic Hierarchy Process (AHP). The AHP can be used properly as a decision-making technique to weigh and rank for effective allocation of water resources (alternatives) with maximum priority and sustainable utilization in Egypt. To accomplish our objective, Egypt was divided into five zones based on natural factors and population concentration to identify the best water resource for each zone. It was found that the Nile River is the best alternative for the Upper Nile zone, while desalination is the least favorable option. The Nile River is the optimal choice in the Nile Delta zone, and desalination is the least preferred option. In the Western Desert, groundwater emerges as the top choice, while desalination is considered the least favorable alternative. Desalination is the best alternative for the Red Sea zone, while Agriculture Drainage is deemed the least suitable option. In the North Coast zone, desalination is preferred, and agriculture drainage is the least favorable option.

Keywords: Decision-making process; Egypt; Fuzzy Analytic Hierarchy Process; Multi-criteria Analysis; Sustainability; Water Resource

1. Introduction

The water resources system in Egypt is characterized by a high degree of complexity and inherent uncertainty. In addition, the fluctuation of water supplies in Egypt is a significant challenge that significantly hinders progress in social and economic development. According to the United Nations Environment Program [1], Egypt has faced a considerable risk of water scarcity since the 1990s. Egypt is characterized by its arid landscape and heavy reliance on the Nile River as its principal water source. It is currently suffering from water stress resulting from rapid population expansion, limited water supplies, and increasing competition for water resources from countries in the upper Nile Basin. The impact of climate change on the discharge of the Nile River represents an additional obstacle to the management of water resources in Egypt. Since the 1990s, Egypt faced a major challenge because of the widening disparity between its limited water resources and the growing demand resulting from a population that exceeded 100 million people as of 2020. Therefore, it has become necessary to use decision-making methodologies to allocate water resources. Available resources effectively meet the country's water needs.

The decision-making process involves identifying the most suitable course of action from a limited range of realistic alternatives; the objective is to satisfy specific target criteria. Numerous decisions can be classified as Multicriteria Decision-Making (MCDM) dilemmas [2]-[7]. The conventional approach to decision analysis involves the identification of decision-makers, criteria, and alternatives. A decision matrix is then constructed based on the assessments made by the decision-makers regarding the performance of the alternatives concerning the requirements. The optimal alternative is determined after applying decision rules [8]. Multicriteria analysis is a decision-making tool that aids in evaluating and selecting options based on multiple criteria.

Rousta and Araghinejad [9] analyzed to demonstrate the feasibility of developing a Decision Support System (DSS) that can be tailored to the specific requirements of the Mubuku Casework, considering factors such as data availability and the prevailing socio-economic conditions. The dynamic nature of a decision advice System (DSS) enables policymakers to get advice and guidance in achieving optimal water management and cropping patterns.

The GIS technologies facilitate decision-making based on their analytical capabilities with spatial information. In addition, many are equipped with a graphical user interface, which increases the decision-makers comprehension of the spatial information involved in the problem being addressed. Based on these two potential additions to the decision-making process, a GIS is often included as a major component in developing Decision Support Systems (DSS) [9].

An Alternative Evaluation Index (AEI) involves assessing many alternatives using both the hydrological simulation program in FORTRAN (HSPF) and multicriteria decision-making (MCDM) methodologies to establish their respective priorities. The HSPF model formulation involves conducting sensitivity assessments on water quantity (precisely peak discharge and total volume) and water quality (specifically BOD peak concentrations and total loads) [10].

There are numerous MCA methods, each of which has a unique strategy. Since the 1960s, numerous techniques have been developed to overcome MCA concerns. Various strategies exist for resolving multicriteria decision-making (MCDM) issues: Outranking approaches such as ELECTRE (ELimination Et Choix Traduisant la REalité), created by Bernard Roy in 1968. It is a non-compensatory approach to MCD problems and tries to compensate for one of the drawbacks of compensatory additive methods. In a compensatory method, given a set of alternatives ranked according to a set of criteria, if one alternative has a very bad score in one criterion, this could be compensated by an excellent score in a different criterion [11].

PROMETHEE was proposed by Brans in 1982 and further extended by Brans and Smet [12]. It is based on an outranking strategy, which ranks and selects one or a set of alternative actions from all feasible alternative solutions while considering numerous sets of criteria that often conflict. The outranking strategy compares parameter alternatives and creates a preferential function to compare alternative pairs on each criterion [13].

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method is a multicriteria decision-making technique that applies a weighting value to each criterion. This method uses the principle that the chosen alternative should have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution. So, available alternatives are sorted by their distance to the positive ideal solution, with the best alternative at the top having the lowest divergence from the ideal solution [14].

The Multi-Attribute Utility Theory (MAUT) evaluates alternatives by the weighted addition of their values concerning their relevant attributes. This technique requires the decision-maker to assess the alternatives on each value dimension (called attribute) separately. The previously discussed techniques were not selected because those approaches require thresholds that are unavailable for these instruments, and the outranking method prevents the direct identification of the alternative's strengths and weaknesses. However, customized techniques such as tailored methods (i.e., Simple Multi-Attribute Rating Technique, SMART) are comprehensive models for decision-makers to account for qualitative and quantitative things. A decision-making model with SMART tries to cover any shortfall from the previous model without computerization [15].

Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH) is a humanistic, interactive, and constructive approach to building a quantitative model of values based on qualitative (verbal) difference judgments. It facilitates the path from ordinal to cardinal preference modeling, namely analyzing judgmental inconsistency and offering suggestions to move the process forward [16]. It is also developed or customized for specific decision problems or contexts. Tailored methods may lack a robust validation or evaluation framework compared to more established and widely used MCA methods [17]. The Analytic Hierarchy Process (AHP) [18] is adopted among the MCA techniques in this work.

The Analytic Hierarchy Process (AHP) was formulated by Thomas Saaty in the 1980s and has since been widely employed in decision-making processes involving complex scenarios. It is particularly applicable when individuals collaborate to reach decisions that have long-term consequences, relying on human perception, judgment, and outcomes [19]. The AHP weighting method exhibited a significant increase in usage over twelve years. In 2012, there were 260 retrieval instances, compared to only 35 in the year 2000. This indicates a substantial growth in application, with the usage in 2012 being almost eight times more than that in 2000. It is also informed by the complexities in making decisions about water resources, particularly in the face of escalating competition for water access [20].

The present work will employ the AHP to assign weights and rankings to the various alternatives. It offers a systematic framework for decision-making, facilitating the efficient organization and analysis of intricate problems for individuals or groups [21]. The AHP is characterized by its adaptability, allowing for flexibility in its application. Additionally, the AHP provides a mathematical structure that enables the evaluation of the consistency of judgments made by decision-makers. Furthermore, the AHP empowers decision-makers to conduct sensitivity analysis, enabling the assessment of how modifications in criteria weights or judgments impact the overall rankings of alternatives.

Some works used different analyses to reach the same objective. For example, the study in [22] used heuristic optimization based on a cost-benefit analysis for residential areas. An analysis of the Rutba City casework in Iraq was conducted for this objective. The results demonstrated the applicability and viability of the optimization model utilizing the modified Clonal to identify the best water supply in terms of the cost-benefit ratio. The authors of [23] used two different cost-benefit functions and compared them to determine the optimum water resources for supplying the water of Rutba City.

The AHP can be employed to make decisions for problems characterized by issues of multiple stakeholders, significant expense (dealing with a large number of resources), and long-term decisions. It provides solid evidence to support decisions [18], [24].

2. Problem Statement

Egypt started to face the threat of water scarcity. Egypt, a dehydrated nation that depends on the Nile River as its primary water source, is experiencing a water shortage due to its expanding population, scarce resources, and heightened competition from the nations that make up the upper Nile Basin for water. The impact of climate change on the Nile's flow is another issue facing Egypt's water supplies. Egypt's biggest difficulty since the 1990s has been the fast-widening disparity between the country's limited water supplies and the country's growing population, which will probably exceed 100 million by 2020. Therefore, work needs to allocate different water resources to cover our consumption. (So, there is a need for a decisive water resource management approach of proper utilization and allocation).

3. Material and Methods

Decision techniques (namely, the AHP) help allocate water sources to reach maximum priority and more sustainable utilization in Egypt by breaking down the decision-making process into subsequent stages. The initial step involves formulating a clear definition of the problem at hand and identifying the specific type of information being sought to address the problem effectively. The decision hierarchy should be structured top-down, beginning with the overarching purpose of the choice; this should be followed by the objectives, which provide a broad viewpoint. The intermediate levels should consist of criteria on which succeeding elements depend. Finally, the lowest level should have a set of alternatives.

To conduct a comparative analysis, a set of matrices for pairwise comparisons must be generated. Each element inside a higher level compares the elements within the immediately lower level to itself.

The weights for the priorities in the subsequent lower level are assigned based on the priorities derived from the comparisons. Execute this methodology for every individual element. Subsequently, the weighted values for each constituent inside the lower level should be computed, followed by the determination of their collective priority, sometimes referred to as the overall or global priority. Continue with the iterative process of assessing and combining the many options until the final rankings of the alternatives at the lowest level are achieved.

The AHP) technique consists of a sequence of steps to create a hierarchical form of three levels. The first level represents the objective, the second level encompasses the criteria, and the third level pertains to the attribute level switch, which can be succinctly summarized as follows: [18] [25].

i. The nine-scale technique is used to allocate each component inside the comparison matrix $An{\times}n$, where n represents the total number of options. The nine-scale levels are Equivalent Importance, weak or slight, moderate or moderate plus, strong, strong plus, very strong, strongly favoring one activity over another, very strong, and extreme importance.

ii. Calculating the significance ranking indicator (r_i) using equation (1):

$$r_i = \sum_{j=1}^{n} a_{ij} \qquad (i = 1,2,\dots\dots,n) \qquad (1)$$

Where and represents each item of the comparison matrix $An{\times}n$.

iii. Analyzing the decision matrix $Bn{\times}n$ and give the following labels to each matrix item b_{ij}

$$b_{ij} = \begin{cases} \dfrac{r_i - r_j}{r_{max} - r_{min}} \times (k_m - 1) + 1 & r_i \geq r_j \\ \left[\dfrac{|r_i - r_j|}{r_{max} - r_{min}} \times (k_m - 1) + 1\right]^{-1} & r_i < r_j \end{cases}$$

$$(i, j) = 1,2,3, \dots\dots\dots n) \qquad (2)$$

Where r_j is the ranking indicator, r_{max} is the maximum amount of the ranking indicator, and r_{min} is the minimum amount. K_m is calculated by equation (3):

$$k_m = \frac{r_{max}}{r_{min}} \qquad (3)$$

iv. Creating the optimum transferal matrix $Cn \times n$, and each matrix element is donated by C_{ij} and evaluated using equation (4):

$$C_{ij} = \frac{1}{n}\sum_{k=1}^{n} log\,\frac{b_{ik}}{b_{jk}} \qquad (i = 1,2,\dots\dots, n) \qquad (4)$$

v. Creating the quasi-optimum consistent matrix, $D_{n\times n}$, where every matrix element is donated by d_{ij} and calculated using equation (5):

$$d_{ij} = 10c_{ij} \qquad (i, j = 1, 2,\dots\dots, n) \qquad (5)$$

vi. For matrix $D_{n\times n}$, the eigenvector having the highest Eigenvalue is determined. After standardization, the weight ω_i of a piece factor can be obtained. The weight vector is formed by adding the weights of each element following equation (6):

$$\omega = (\omega_1, \omega_2, \omega_3, \dots, \omega_n)\,T \qquad (6)$$

vii. Calculating the highest Eigenvalue of the matrix (λ_{max}) using equation (7):

$$\lambda_{max} = \sum_{j=1}^{n} \frac{(s.w)_j}{(m.w)_j} \qquad (j = 1,2, \dots\dots, n) \qquad (7)$$

Where S means the matrix of pairwise comparison and ω is the eigenvector of the matrix.

viii. Using equation (8), determine the consistency index (CI):

$$CI = \frac{\lambda\,max - n}{n-1} \qquad (8)$$

xi. Determining the consistency ratio (CR) using equation (9):

$$CR = \frac{CI}{RI} \qquad (9)$$

Where a Saaty pairwise comparison matrix random model's average CI values are used to calculate RI, as shown in

Table **1**.

Table 1. The RI Values

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

4. Results

The utilization of AHP aids in allocating water sources in Egypt. The work aims to achieve maximum priority and promote sustainable utilization. Several factors influence the selection of appropriate water resources. These include the quality of the influent water, the quality of the water produced, the distance of the water supply, the topography of cities and their surroundings, the elevation of the source supply, social, political, and cultural considerations, construction costs, operation and maintenance costs, environmental conditions, and the in-stream and withdrawal uses of water. The cost associated with the transportation of water, the quantity of water generated, and the sustainability of resources. The selection of these factors was informed by prior work [26].

Subsequently, a survey was administered using a questionnaire on the Google App to determine the importance of each factor in choosing the ideal alternative water resources. The questionnaire was presented to experts in the field, and the relative weight of each element was determined through analysis of the survey findings. The outcomes are shown in Table 2.

Table 2. Relative Weight for Water Resource Selection Factor [26]

Factor influencing water resource selection	Relative Weight
Source Sustainability	9.84%
Quantity of water	9.30%
Operation and maintenance cost	8.68%
Environmental Conditions	8.32%
Water quality (produced water)	8.42%
In-stream and Withdrawal Uses of Water	7.68%
Socio-political and cultural considerations	7.61%
Cost of transporting water	7.18%
Quality of water (influent)	7.17%
Tab Elevation of the source of water supply	6.61%
Construction cost	6.63%
Distance of water supply source	6.48%
Topography of the city and its surroundings	6.10%
Sum	100.00%

Table 3 in the following section. To know the impact percent of each resource concerning all factors, equal sum (weight of each factor × weight of the resource for all factors) *100.

To achieve accurate outcomes, this work has divided Egypt into five distinct zones as illustrated in Figure 1: Zone 1, referred to as Upper Egypt; Zone 2, known as Lower Egypt; Zone 3, encompassing the Western Desert; Zone 4, covering the Red Sea Area; and Zone 5, denoting the North Coast. These divisions have been established based on natural characteristics and population density. Implementing this division helps ascertain the optimal water resource for each Zone.

Figure 1. Works Zones: Zone 1, Upper Egypt; Zone 2, Lower Egypt; Zone 3, Western Desert; Zone 4, Red Sea Area; And Zone 5, North Coast

4.1. Zone 1: Upper Egypt

Upper Egypt refers to the southern region of Egypt, encompassing the Nile River valley situated south of the Delta and the 30th parallel North. This geographical area includes the entirety of the Nile River valley extending from Cairo to the south, ultimately reaching Lake Nasser, which was created as a result of the construction of the Aswan High Dam. By implementing the procedures of AHP fuzzy analysis on Zone (1), as demonstrated in section 3, the corresponding outcomes were obtained and illustrated in

Table 3. Relative Weight of Resources Concerning Different Factors for Upper Egypt

Water resource / Factors	Relative Weight	The Relative Weight of Water Resources to the Factors Affecting Their Choice					
		Nile River	Desalination	Rains	Wastewater Treatment	Agriculture Drainage	Groundwater

Topography of the city and its surroundings	6.10%	31.70%	4.50%	4.50%	13.60%	22.80%	22.80%
Distance of water supply source	6.48%	30.40%	4.30%	4.30%	8.70%	21.70%	30.40%
Elevation of the source of water supply	6.61%	26.90%	3.90%	3.90%	26.90%	26.90%	11.60%
Construction cost	6.63%	23.70%	7.90%	23.70 %	13.20%	13.20%	18.30%
Quality of water (influent)	7.17%	36.00%	4.00%	4.00%	12.00%	20.10%	24.00%
Cost of transporting water	7.18%	30.50%	4.30%	4.30%	13.00%	21.80%	26.00%
Social-political and cultural considerations	7.61%	34.80%	5.00%	5.00%	15.00%	25.20%	15.00%
In-stream and Withdrawal Uses of Water	7.68%	29.00%	3.20%	3.20%	16.10%	19.40%	29.00%
Environmental Conditions	8.32%	36.00%	4.00%	4.00%	8.00%	12.00%	36.00%
Water quality (produced water)	8.42%	36.00%	4.00%	4.00%	12.00%	20.10%	24.00%
Operation and maintenance cost	8.68%	23.70%	7.90%	23.70 %	13.20%	13.20%	18.30%
Quantity of water	9.30%	34.70%	3.80%	3.80%	19.30%	26.80%	11.50%
Source Sustainability	9.84%	37.50%	4.20%	4.20%	12.40%	20.90%	20.90%
% IMPACT		31.9%	4.7%	7.1%	14.1%	20.2%	22%

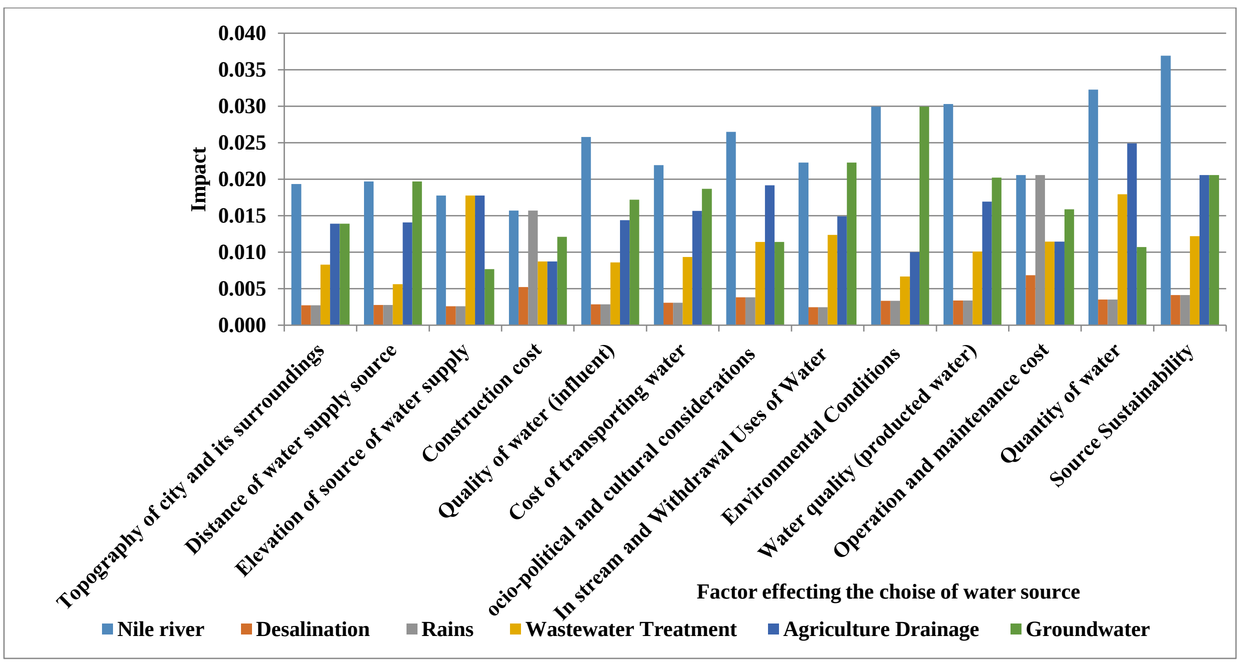

Figure 2. Impacts of Each Resource Concerning Each Factor for The Upper Nile Zone

Error! Reference source not found. and Figure 2 show the order of water resources (alternatives) for the Upper Nile Zone from the most favorable to the least favorable option for this area. The water resource alternatives were found to be arranged in the following order: Nile River, groundwater, agriculture drainage, water treatment, rain, and desalination.

Fig. 3 shows that the Nile River is the best choice, with the highest impact at 31.9%. It fulfills most of the factors such as being a sustainable resource with plenty of water, the quality of water produced suitable for all usage, suitable environmental conditions, a close distance to the resource, low cost of transport, and low cost of construction.

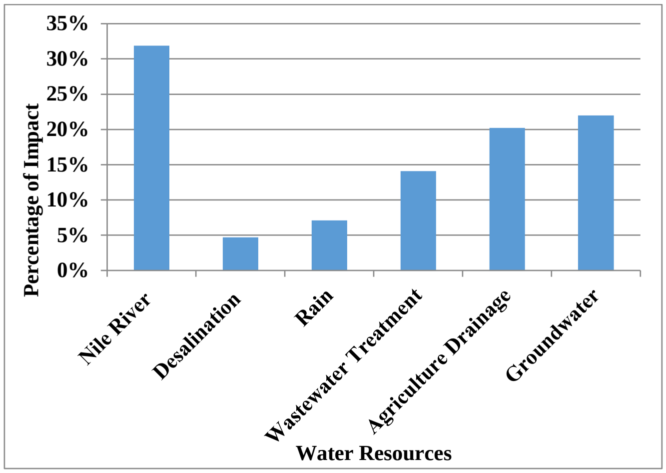

Figure 3. Impact Percent of The Water Resources (Alternatives) For the Upper Nile Zone

Groundwater ranks second in terms of its alternative potential, accounting for 22% of its overall influence, following the Nile River. Due to its exceptional environmental safety and suitability to any environmental condition, the water produced is high quality and suited for all purposes. Additionally, the closeness of the location minimizes transportation costs. On the other hand, the relative availability of groundwater as a sustainable resource differs from the Nile River's. The quantity of underground water is lower than that of the river, and there is a significant elevation difference between the groundwater and its utilization. Additionally, the topography in this area is very challenging. These factors contribute to the underground water source being ranked second after the Nile.

Agricultural drainage is the third option, with a 20.2% impact. This is because the water used in agriculture can be treated and reused for irrigation purposes, making it a sustainable resource. However, it is unsuitable for all purposes and requires additional costs for collection and treatment.

The least favorable option for addressing water scarcity in this area is desalination, which has an impact of 4.7% due to the absence of a nearby sea. This makes it challenging and expensive to transport the necessary resources for construction, operation, and transportation.

4.2. Zone 2: Nile Delta

The Nile Delta is formed in Lower Egypt as the Nile River spreads and drains into the Mediterranean Sea. Spanning from Alexandria in the west to Port Said in the East, the river delta is an enormous region of land that stretches for 240 km along the Mediterranean coastline. Notably, it is one of the largest river deltas in the world and is known for its fertile soil, making it a prosperous agricultural zone. The Delta spans approximately 160 km from North to South to just below Cairo [27]. By implementing the procedures of AHP fuzzy analysis on Zone (2), as demonstrated in section 3, the corresponding outcomes were obtained and illustrated in

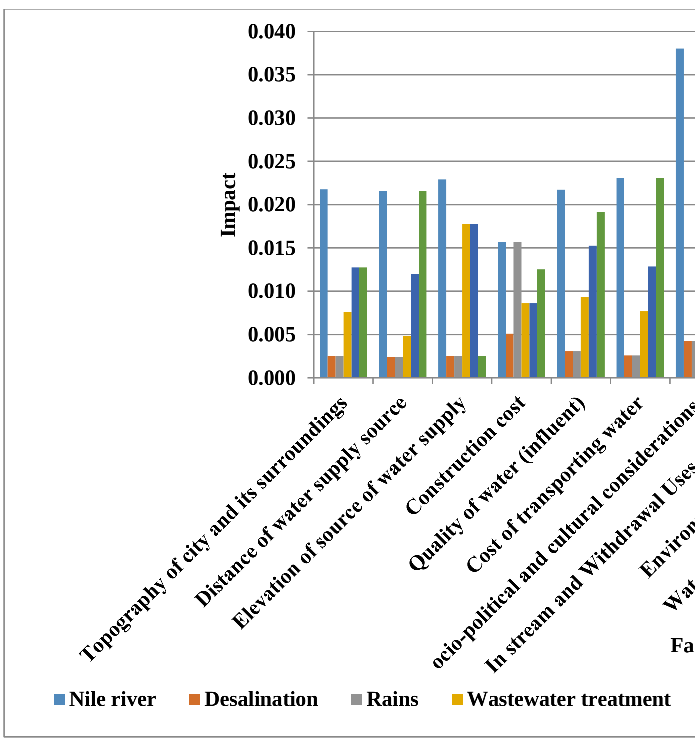

Figure 4. Impacts of Each Resource Concerning Each Factor for The Nile Delta

Table 4 in the following section. **Error! Reference source not found.** and Figure 4 show the order of water resources (alternatives) for the Nile Delta Zone from the most favorable to the least favorable option for this area.

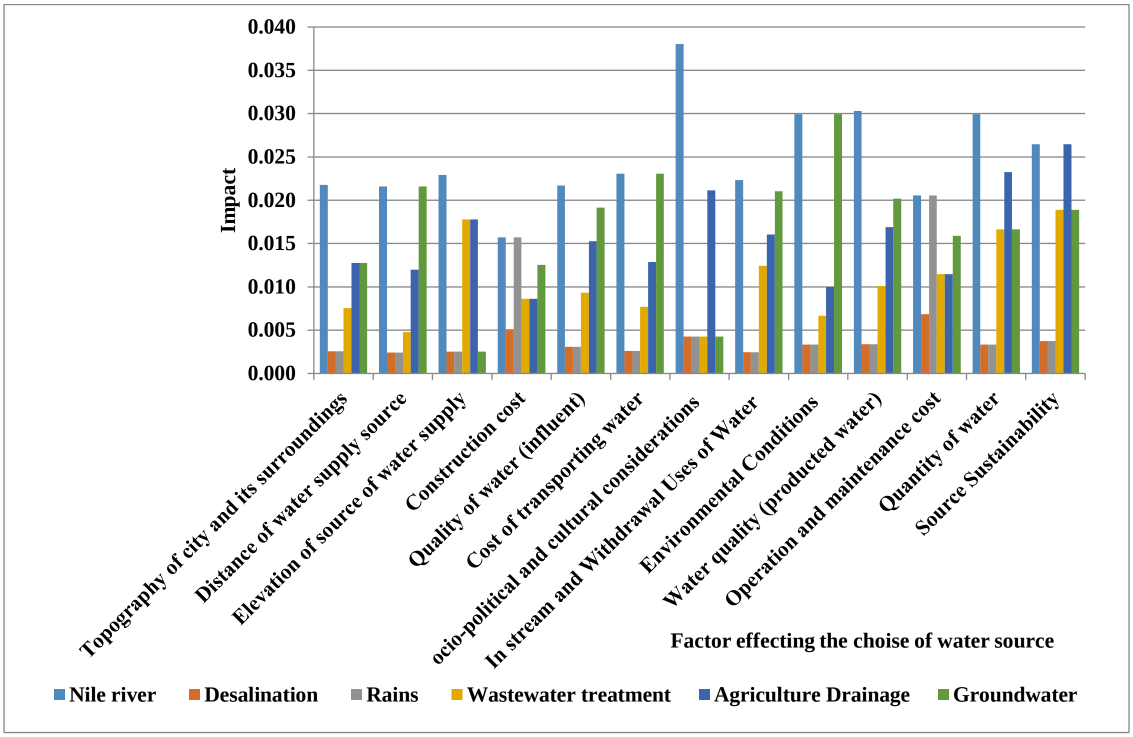

Figure 4. Impacts of Each Resource Concerning Each Factor for The Nile Delta

Table 4. Relative Weight of Resources Concerning Different Factors for The Nile Delta Zone

Water Resource / Factors	Relative Weight	The Relative Weight of Water Resources to the Factors Affecting Their Choice					
		Nile River	Desalination	Rains	Wastewater Treatment	Agriculture Drainage	Groundwater
Topography of the city and its surroundings	6.10%	35.70%	4.20%	4.20%	12.40%	20.90%	20.90%
Distance of water supply source	6.48%	33.30%	3.70%	3.70%	7.40%	18.50%	33.30%
Elevation of the source of water supply	6.61%	34.70%	3.80%	3.80%	26.90%	26.90%	3.80%
Construction cost	6.63%	23.70%	7.70%	23.70%	13.00%	13.00%	18.90%
Quality of water (influent)	7.17%	30.30%	4.30%	4.30%	13.00%	21.30%	26.70%
Cost of transporting water	7.18%	32.10%	3.60%	3.60%	10.70%	17.90%	32.10%
Social-political and cultural considerations	7.61%	50.00%	5.60%	5.60%	5.60%	27.80%	5.60%
In-stream and Withdrawal Uses of Water	7.68%	29.10%	3.20%	3.20%	16.20%	20.90%	27.40%
Environmental Conditions	8.32%	36.00%	4.00%	4.00%	8.00%	12.00%	36.00%
Water quality (produced water)	8.42%	36.00%	4.00%	4.00%	12.00%	20.10%	24.00%
Operation and maintenance cost	8.68%	23.70%	7.90%	23.70%	13.20%	13.20%	18.30%
Quantity of water	9.30%	32.20%	3.60%	3.60%	17.90%	25.00%	17.90%
Source Sustainability	9.84%	26.90%	3.80%	3.80%	19.20%	26.90%	19.20%
%Impact		32.4%	4.6%	7.0%	13.6%	20.5%	21.8%

The water resource alternatives were found to be arranged in the following order: Nile River, groundwater, agriculture Drainage, water treatment, Rainwater, and desalination.

As illustrated in Figure 5, The Nile River is the optimal water source for the Nile Delta zone due to its significant impact of 32.4%. It satisfies various criteria, such as being a sustainable resource with abundant water, having minimal political and cultural restrictions, producing high-quality water suitable for all purposes, being located close to the area of use resulting in low transportation costs, having low construction costs, being environmentally safe, and being suitable for any environmental condition.

Groundwater is the second alternative to the Nile River, with an impact of 21.8%. It offers suitable environmental conditions and produces high-quality water that can be used for various purposes. Additionally, the proximity of groundwater sources results in low transportation costs. While it is a sustainable resource, it differs from the Nile River in quantity, as the amount of underground water is less. Furthermore, there is a significant elevation difference between the groundwater and its utilization.

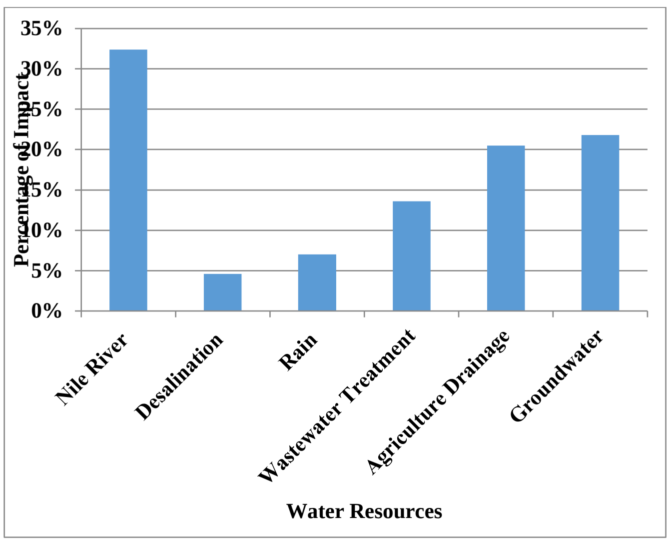

Figure 5. Impact Percent of The Water Resources (Alternatives) For the Nile Delta Zone

Like the Upper Nile, agricultural drainage ranks third in impact, with an effect of 20.5%. This region is primarily agricultural, allowing for water reuse for irrigation purposes after undergoing treatment. However, the water quality is unsuitable for all purposes, and the collection and treatment process incur additional costs.

Desalination is the least favorable option for the Nile Delta zone, with a significant impact of 4.6%. This is due to the absence of a nearby sea, making it challenging and expensive for construction, operation, and transportation costs.

4.3. Zone 3: West Desert

The Western Desert of Egypt is a section of the Sahara Desert located west of the river Nile. It spans from the Libyan border to the south of the Mediterranean Sea and extends to the Sudanese border. It is named in contrast to the Eastern Desert, which extends easterly from the Nile River to the Red Sea. Most of the Western Desert is characterized by rugged topography, except for a sandy desert area known as the Great Sand Sea, situated to the west adjacent to the Libyan border. The desert has an area of 680,650 square kilometers, approximately two-thirds of the country's total land area. The nation's peak altitude is 1,000 meters on the Golf Kebir plateau, which is positioned in the remote southwestern region of the country, adjacent to the borders of Egypt, Sudan, and Libya. The Western Desert is characterized by a complete absence of plant life and human settlement, except for a sequence of oases that extend in a curving formation from Siwa in the northwest to Kharga in the south. It has lately functioned as a battleground, specifically during the Second World War [28].

Implementing the procedures of AHP fuzzy analysis on Zone (3), as demonstrated in section 3, obtained the corresponding outcomes, which are illustrated in

Table 5 in the following section.

Table 5. Relative Weight of Resources Concerning Different Factors for The Western Desert Zone

WATER RESOURCE / Factors	Relative Weight	The Relative Weight of Water Resources to the Factors Affecting Their Choice					
		Nile River	Desalination	Rains	Wastewater Treatment	Agriculture Drainage	Groundwater
Topography of the city and its surroundings	6.10%	10.00 %	10.00%	30.00 %	10.00%	10.00%	30.00%
Distance of water supply source	6.48%	4.50 %	4.50%	22.70 %	4.50%	22.70%	40.90%
Elevation of the source of water supply	6.61%	4.20 %	4.20%	20.80 %	4.20%	29.10%	37.60%
Construction cost	6.63%	23.70 %	7.90%	23.70 %	13.20%	13.20%	18.30%

Quality of water (influent)	7.17%	5.00%	5.00%	25.10%	5.00%	14.90%	45.00%
Cost of transporting water	7.18%	7.10%	7.10%	21.30%	7.10%	21.30%	35.90%
Social-political and cultural considerations	7.61%	12.50%	12.50%	12.50%	12.50%	12.50%	37.50%
In-stream and Withdrawal Uses of Water	7.68%	4.50%	4.50%	22.70%	4.50%	22.70%	40.90%
Environmental Conditions	8.32%	5.00%	5.00%	25.10%	5.00%	14.90%	45.00%
Water quality (produced water)	8.42%	5.00%	5.00%	25.10%	5.00%	14.90%	45.00%
Operation and maintenance cost	8.68%	23.70%	7.90%	23.70%	13.20%	13.20%	18.30%
Quantity of water	9.30%	5.00%	5.00%	25.20%	15.00%	15.00%	34.80%
Source Sustainability	9.84%	7.10%	7.10%	21.50%	7.10%	7.10%	49.90%
%Impact		9.0%	6.6%	23.0%	8.3%	15.9%	37.2%

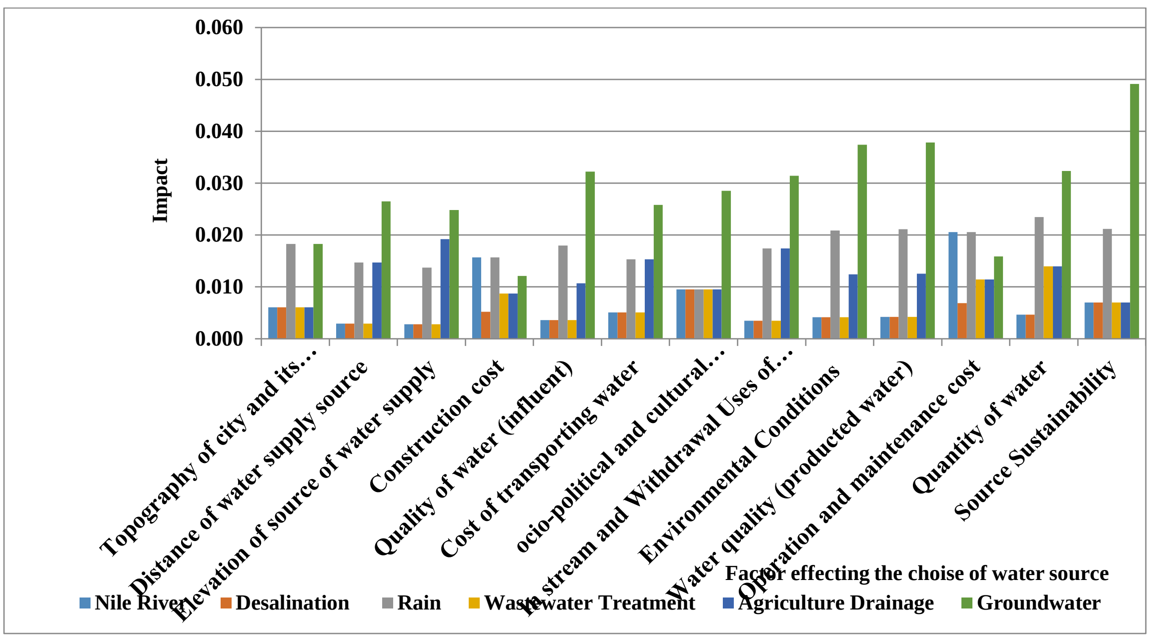

Figure 6. Impact of each resource concerning each factor for the Western Desert Zone

Table 5 and Figure 6 show the order of water resources (alternatives) for the western desert zone from the most favorable to the least favorable. The water resource alternatives were found to be arranged in the following order: groundwater, rain, agricultural drainage, Nile River, water treatment, and desalination.

Figure 7 demonstrates that groundwater is the optimal option for the western desert since it has the most impact factor of 37.2% due to its sustainability as a resource. The water quantity in this location is sufficient for the tiny population, and the water quality is appropriate. Additionally, the proposed construction costs are cheap, the operating expenses are low, and the environmental conditions are suitable. The second alternative for the western desert is rain, with an impact of 23%. This is due to the suitability of water quality for all proposals and the low construction and operating costs, which are suitable for the desert environment and plants. However, it differs from the first alternative as rain is not a sustainable resource. On the other hand, desalination is the least favorable option, with an impact of 6.6%. This is due to the distance of the sea from the region and the substantial costs associated with building, operation, and transportation.

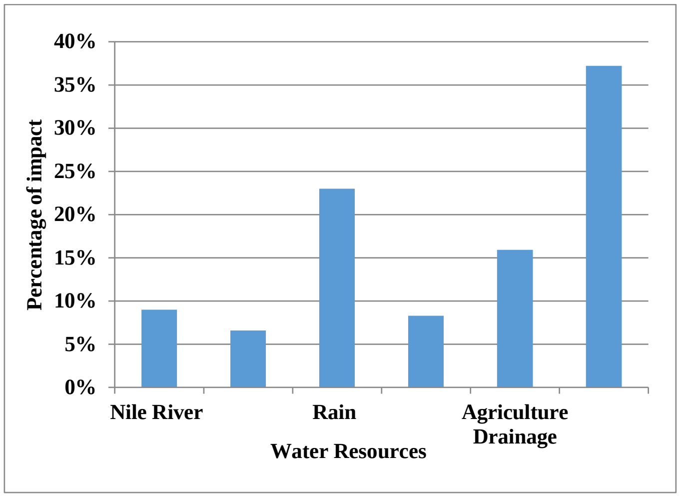

Figure 7. Impact Percent of The Water Resources (Alternatives) For the Western Desert Zone

4.4. Zone 4: Red Sea

The Red Sea and the Gulf of Suez region, which borders on the east, are from the northern and southern boundaries of the Red Sea coastal desert. It encompasses the Red Sea Hills, a group of coastal mountains that run parallel to the coast, and a small coastal strip. The Eastern Desert, a component of the extremely dry Sahara Desert ecoregion, borders the Egyptian section on the west. The Sahelian Acacia savanna to the south and the South Saharan steppe to the west define the boundaries of the Sudanese part.

Implementing the procedures of AHP fuzzy analysis on Zone (4), as demonstrated in section 3, obtained the corresponding outcomes, which are illustrated in Table 6 in the following section.

Table 6. Relative Weight of Resources concerning Different Factors for The Red Sea Zone

WATER RESOURCE / Factors	Relative Weight	The Relative Weight of Water Resources to the Factors Affecting Their Choice					
		Nile River	Desalination	Rains	Wastewater Treatment	Agriculture Drainage	Groundwater
Topography of the city and its surroundings	**6.10%**	5.00%	25.10%	14.80 %	25.10%	5.00%	25.10%
Distance of water supply source	**6.48%**	3.80%	34.70%	11.50 %	26.80%	3.80%	19.30%
Elevation of the source of water supply	**6.61%**	3.80%	34.70%	11.50 %	26.80%	3.80%	19.30%
Construction cost	**6.63%**	23.70%	7.70%	23.70 %	13.00%	13.00%	18.90%
Quality of water (influent)	**7.17%**	12.40%	37.50%	12.40 %	12.40%	4.20%	21.00%
Cost of transporting water	**7.18%**	4.20%	29.10%	12.50 %	29.10%	4.20%	20.90%
Social-political and cultural considerations	**7.61%**	24.80%	32.20%	10.70 %	10.70%	3.60%	18.00%
In-stream and Withdrawal Uses of Water	**7.68%**	24.80%	32.20%	10.70 %	10.70%	3.60%	18.00%
Environmental Conditions	**8.32%**	36.00%	4.00%	4.00 %	8.00%	12.00%	36.00%
Water quality (produced water)	**8.42%**	28.10%	28.10%	9.30 %	15.70%	3.10%	15.70%
Operation and maintenance cost	**8.68%**	23.70%	7.70%	23.70 %	13.00%	13.00%	18.90%
Quantity of water	**9.30%**	17.90%	32.10%	17.90 %	17.90%	3.60%	10.60%
Source Sustainability	**9.84%**	12.40%	37.50%	4.20 %	20.90%	4.20%	20.90%
%Impact		**17.3%**	**26.3%**	**12.6 %**	**17.7%**	**6.0%**	**20.1%**

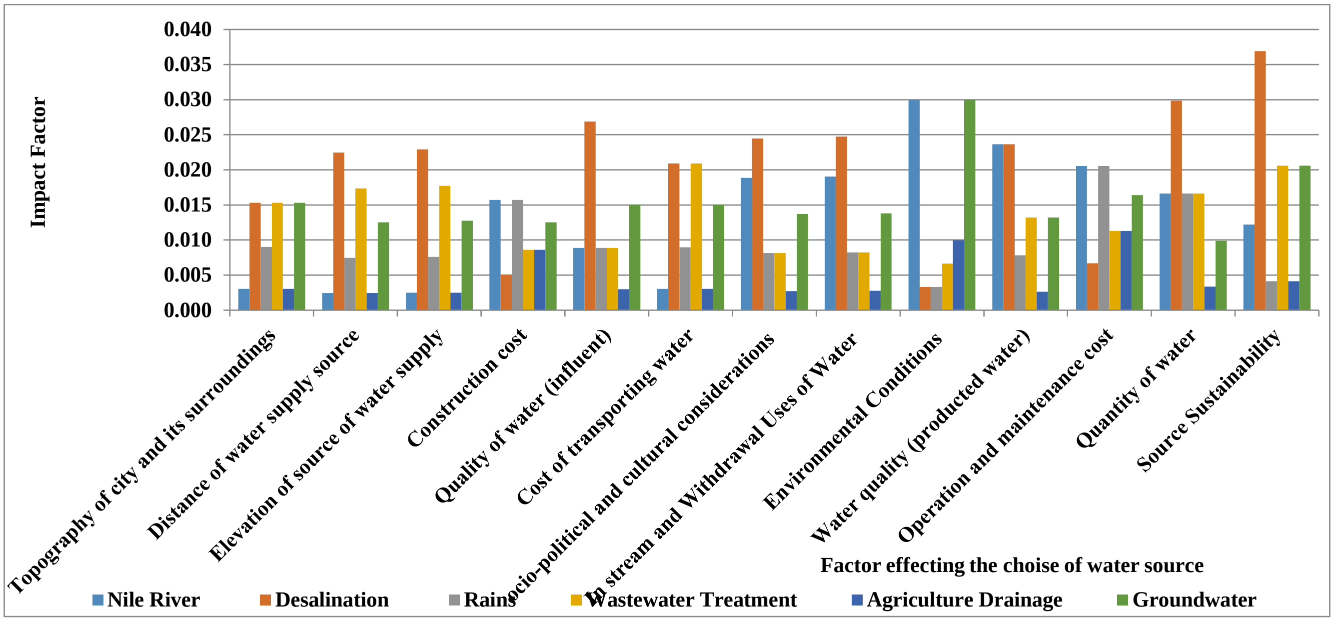

Figure 8. Impact of each resource concerning each factor for the Red Sea Zone

Error! Reference source not found. and Figure 8 show the order of water resources (alternatives) for the Red Sea zone from the most favorable to the least favorable option. The water resource alternatives were found to be arranged in the following order: desalination, groundwater, wastewater, Nile River, rain, and agriculture drainage.

As shown in Figure 9, desalination is the optimal option for the Red Sea zone, with the highest impact of 26.3%, as it meets most selection factors. Desalination is considered a sustainable resource that provides a stable water supply. The water produced meets the requirements for all types of usage. Additionally, the closeness of resources to the usage area leads to minimal transportation expenses. Nevertheless, the challenging geography of the region, characterized by the proximity of the Red Sea highlands to the coasts, poses significant difficulties.

Groundwater is a viable alternative to desalination, with an impact of 20.1% due to suitable environmental conditions. The quality of groundwater is ideal for all purposes, and although it is not as easily accessible as seawater, the transportation cost is relatively low. Groundwater is a sustainable resource but less abundant than seawater, so it is considered a secondary option after desalination. Agricultural drainage is the most unfavorable option for the Red Sea Zone, as it impacts 6% due to the absence of agricultural activities and the lack of drainage work.

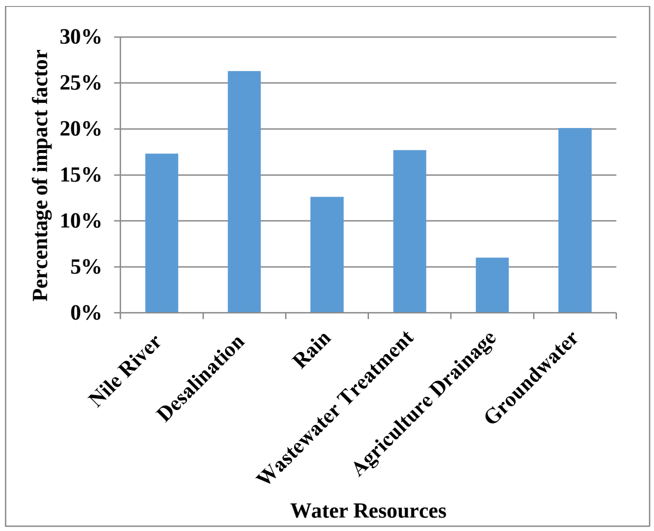

Figure 9. Impact Percent of The Water Resources (Alternatives) For the Red Sea Zone

4.5. Zone 5: North Coast

The North Coast extends about 1,050 km along the Mediterranean Sea, covering the entire northern territory of Egypt. It is one of the longest Mediterranean coastlines and is popularly known for its snow-white sand beaches and crystal-clear seawater.

Table 7. Relative Weight of Resources concerning Different Factors for The North Coast Zone

Water Resource / Factors	Relative Weight	The Relative Weight of Water Resources to the Factors Affecting Their Choice					
		Nile River	Desalination	Rains	Wastewater Treatment	Agriculture Drainage	Ground-water
Topography of the city and its surroundings	**6.10%**	16.75%	30.00%	10.00%	23.20%	3.30%	16.75%

Distance of water supply source	**6.48%**	10.70%	32.20%	10.70%	24.80%	0.04%	18.00%
Elevation of the source of water supply	**6.61%**	16.75%	30.00%	10.00%	23.20%	3.30%	16.75%
Construction cost	**6.63%**	23.70%	7.70%	23.70%	13.00%	13.00%	18.90%
Quality of water (influent)	**7.17%**	12.40%	37.60%	12.40%	12.40%	4.20%	21.00%
Cost of transporting water	**7.18%**	16.75%	30.00%	10.00%	23.20%	3.30%	16.75%
Social-political and cultural considerations	**7.61%**	23.20%	30.00%	10.00%	16.75%	3.30%	16.75%
In-stream and Withdrawal Uses of Water	**7.68%**	24.80%	32.20%	10.70%	10.70%	3.60%	18.00%
Environmental Conditions	**8.32%**	18.75%	30.00%	10.00%	10.20%	3.30%	27.75%
Water quality (produced water)	**8.42%**	28.10%	28.10%	9.50%	15.60%	3.10%	15.60%
Operation and maintenance cost	**8.68%**	23.70%	7.70%	23.70%	13.00%	13.00%	18.90%
Quantity of water	**9.30%**	11.50%	34.60%	19.50%	11.50%	11.50%	11.50%
Source Sustainability	**9.84%**	11.50%	34.60%	11.50%	19.30%	3.80%	19.30%
%Impact		**18.3%**	**28.2%**	**13.4%**	**16.3%**	**5.7%**	**18.1%**

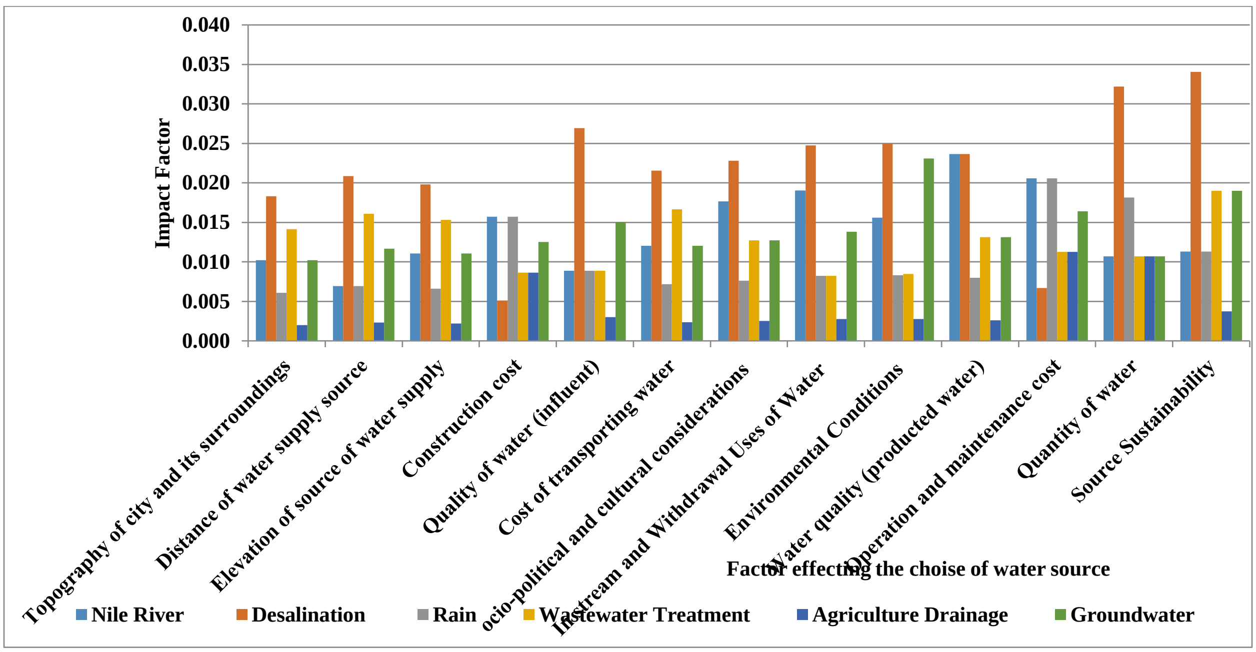

Figure 10. Impact of Each Resource concerning Each Factor for The North Coast Zone

Implementing the procedures of AHP fuzzy analysis on Zone (5), as demonstrated in section 3, obtained the corresponding outcomes, which are illustrated in
Table 7 in the following section.

Table 7 and Figure 10**Figure 8** show the order of water resources (alternatives) for the Red Sea zone from the most favorable to the least favorable option. The water resource alternatives were found to be arranged in the following order: desalination, Nile River, groundwater, wastewater, rain, and agriculture drainage.

As shown in

Figure **11**, desalination is the most effective option in the north coast sea zone, with the highest impact of 28.2%. It satisfies most selection factors as it is a renewable resource abundant in water. The water generated is of high quality and suited for all purposes. Additionally, the resources are located near the location where the water is used, leading to low transportation costs. The building and running costs of this resource are considerable. However, the numerous advantages outweigh this drawback.

The Nile River is the second alternative after desalination, with an impact of 18.3%.

It is a sustainable resource; the quality of water produced is suitable for all usage with suitable environmental conditions, and the cost of construction and operation is low. On the other hand, as the north coast is at the end of the Nile River, the water quantity is low and turbid, so it comes after desalination.

Groundwater comes as a third alternative, after the Nile River, with an impact of 18.1%. Very close to the Nile River, with suitable environmental conditions, the water quality is suitable for all usage. The distance is close but not as close as the Mediterranean Sea, so the transporting cost is considered low. It is a sustainable resource, but it is different from desalination as the quantity of underground water is less than the seawater, which is why it comes third after desalination. The worst alternative for the north coast zone is agricultural drainage, which has an impact of 5.7%. As this Zone is not an agricultural area, there is no drainage, so it is not an alternative for this Zone.

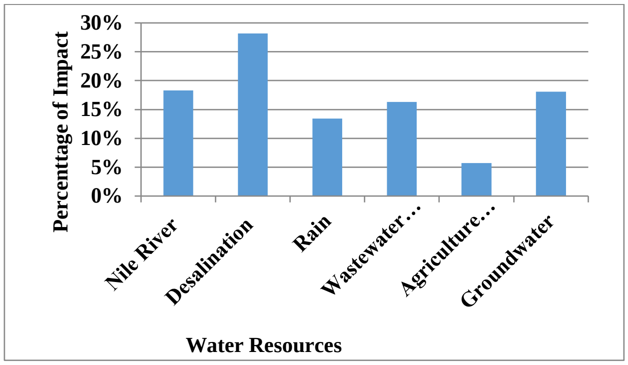

Figure 11. Impact Percent of The Water Resources (Alternatives) For the North Coast Zone

Figure 12. The most suitable alternative for each zone

Fig. 13 illustrates the best source for each of the five regions. Since there is no one way to solve the water crisis without using all of the readily available resources, The Nile zone (zones 1,2) is situated along the river's path so that it can rely on it as our primary water source. However, if the Nile level decreases for any reason, it may depend on the groundwater in the surrounding area. They are a small group of Bedouins in the Western Desert (zone 3). The largest groundwater reservoir on the Libyan border is the Nubian sandstone reservoir. In addition, it was found that coastal regions like the Mediterranean and Red Seas (zones 4,5) are popular tourist destinations and investment areas; investors will not skimp on providing a stable water source for their huge projects by building seawater desalination plants and bearing its high cost, and that why it is the suitable resource for each zone. Additionally, if any zone is deficient, alternate options have been devised for each region based on what is most suitable and nearby.

5. Conclusions

Water is the source of life and essential for the growth of countries. This work used the AHP decision-making analysis to reallocate water resources and determine each zone's best and worst resources. Egypt has been divided into five regions according to the population distribution to achieve proper utilization and sustainable water resources in Egypt. The main conclusions of the present work may be summarized in the following:

The Nile River is the best alternative in the Upper Nile zone, with an impact of 31.9%. Groundwater comes after it, with an impact of 22%, while desalination is the worst alternative, with an impact of 4.7%. In the Nile Delta zone, the Nile River is the best alternative, with an impact of 32.4%, and groundwater comes after it, with an impact of 21.8%. Desalination is the worst alternative at 4.6%. In the Western Desert Zone, groundwater is the best alternative, with an impact of 37.2%, and rain comes after it, with an impact of 23%, while desalination is the worst alternative, with an impact of 6.6%. In the Red Sea Zone, desalination is the best alternative, with an impact of 26.3%; groundwater comes after it, with an impact of 20.1%, while agriculture drainage is the worst alternative, with an impact of 6%. In the North Coast zone, desalination is the best Alternative, with an impact of 28.2%. Nile River comes after it with an impact of 18.3%, and underground has a very close impact with the Nile River with an impact of 18.1%, while agriculture drainage is the worst alternative with an impact of 5.7%.

Acknowledgments

The authors would like to reveal their appreciation and gratitude to the respected reviewers and editors in JEASD for their constructive comments.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Author Contribution Statement

Yara A. Zaki: Proposed the work problem and design.

Yasser El-Elsaie: Developed the theory and performed the computations.

Ibrahim M. Mahdi: Verified the analytical methods.

Ibrahim M.M.: Discussed the results and contributed to the final manuscript.

References

[1] M. Ivanova, "UNEP in Global Environmental Governance: Design, Leadership, Location," *Global Environmental Politics*, vol. 10, no. 1, pp. 30–59, Feb. 2010, doi: https://doi.org/10.1162/glep.2010.10.1.30.

[2] H. Elba, Ibrahim. M. Mahdi, and I. A. Rashid, "Optimum Selection of Concrete Batch Plant (CBP) Location Model Using Analytic Network Process," *American Journal of Engineering Research (AJER)*, vol. 7, no. 3, pp. 206–227, 2018, Available: https://www.ajer.org/papers/Vol-7-issue-3/V0703206217.pdf

[3] I. M. Mahdi, A. M. Ebid, and R. Khallaf, "Decision Support System for Optimum Soft Clay Improvement Technique for Highway Construction Projects," *Ain Shams Engineering Journal*, vol. 11, no. 1, pp. 213–223, Mar. 2020, doi: https://doi.org/10.1016/j.asej.2019.08.007.

[4] I. M. Mahdi, A. H. Khalil, H. A. Mahdi, and D. M. M. Mansour, "Decision Support System for Optimal Bridge' Maintenance," *International Journal of Construction Management*, vol. 22, no. 3, pp. 1–15, Jun. 2019, doi: https://doi.org/10.1080/15623599.2019.1623991.

[5] H. Elhegazy, A. Ebid, I. M. Mahdi, S. Y. A. Haggag, and I. A. Rashid, "Decision Making and Predicting the Cost for the Optimal Structural System of Multi-Story Buildings," *American Journal of Engineering and Applied Sciences*, vol. 14, no. 2, pp. 152–161, Feb. 2021, doi: https://doi.org/10.3844/ajeassp.2021.152.161.

[6] S. Yosr, I. Abd-Elrashed, I. Mahdi, and M. Elmikawi, "A Construction Bid's Markup Factors Identification in Egypt," *Al-Azhar University Civil Engineering Research Magazine (CERM)*, vol. 41, no. 1, pp. 41–48, 2019, Available: http://www.azharcermjournal.com/CERMF1901/P19-01-03.pdf

[7] I. M. Mahdi, H. Arafat, A. M. Ebid, and A. F. El-Kadi, "Decision Model to Identify the Optimum Retaining Wall Type for Restricted Highway Projects Sites," *International Journal of Construction Management*, vol. 23, no. 8, pp. 1–8, Sep. 2021, doi: https://doi.org/10.1080/15623599.2021.1974151.

[8] H. TAHERDOOST, "Decision Making Using the Analytic Hierarchy Process (AHP); a Step by Step Approach," *International Journal of Economics and Management Systems*, vol. 2, pp. 244–246, 2017, Available: http://www.iaras.org/iaras/journals/ijems

[9] B. A. Rousta and S. Araghinejad, "Development of a Multi Criteria Decision Making Tool for a Water Resources Decision Support System," *Water Resources Management*, vol. 29, no. 15, pp. 5713–5727, Sep. 2015, doi: https://doi.org/10.1007/s11269-015-1142-4.

[10] E.-S. Chung and K. S. Lee, "Prioritization of Water Management for Sustainability Using Hydrologic Simulation Model and Multicriteria Decision Making Techniques," *Journal of Environmental Management*, vol. 90, no. 3, pp. 1502–1511, Mar. 2009, doi: https://doi.org/10.1016/j.jenvman.2008.10.008.

[11] M. I. Gomes and N. C. Martins, *Mathematical Models for Decision Making with Multiple Perspectives*. Boca Raton: CRC Press, 2022. Available: https://doi.org/10.1201/9781003015154

[12]J.-P. Brans and Y. De Smet, "PROMETHEE Methods," *Multiple Criteria Decision Analysis*, vol. 233, pp. 187–219, 2016, doi: https://doi.org/10.1007/978-1-4939-3094-4_6.

[13] J. J. Thakkar, *Multicriteria Decision Making*. Singapore: Springer Singapore, 2021. doi: https://doi.org/10.1007/978-981-33-4745-8.

[14] M. A. El-Aghoury, A. M. Ebid, and I. M. Mahdi, "Decision Support System to Select the Optimum Steel Portal Frame Coverage System," *Ain Shams Engineering Journal*, vol. 12, no. 1, pp. 73–82, Mar. 2021, doi: https://doi.org/10.1016/j.asej.2020.07.021.

[15] R. Rsawandi and R. Rahim, "Study of the Simple Multi-Attribute Rating Technique for Decision Support," *Decision-making*, vol. 2, no. 6, pp. 491–494, Dec. 2016, doi: https://doi.org/10.32628/ijsrst162696.

[16] C. A. Bana, J.-M. D. Corte, and Jean-Claude Vansnick, "MACBETH. (Overview of MACBETH Multicriteria Decision Analysis approach)," *International Journal of Information Technology & Decision Making*, vol. 11, no. 2, pp. 359–387, Jan. 2003, Available: https://www.researchgate.net/publication/230674197_MACBETH_Overview_of_MACBETH_multicriteria_decision_analysis_approach#fullTextFileContent

[17] S. Aminbakhsh, M. Gunduz, and R. Sonmez, "Safety Risk Assessment Using Analytic Hierarchy Process (AHP) during Planning and Budgeting of Construction Projects," *Journal of Safety Research*, vol. 46, pp. 99–105, Sep. 2013, doi: https://doi.org/10.1016/j.jsr.2013.05.003.

[18] I. M. Mahdi and K. Alreshaid, "Decision Support System for Selecting the Proper Project Delivery Method Using Analytical Hierarchy Process (AHP)," *International Journal of Project Management*, vol. 23, no. 7, pp. 564–572, Oct. 2005, doi: https://doi.org/10.1016/j.ijproman.2005.05.007.

[19] H. S. Alsamaray, "AHP as Multicriteria Decision-Making Technique, Empirical Study in Cooperative Learning at Gulf University," *European Scientific Journal, ESJ*, vol. 13, no. 13, p. 272, May 2017, doi: https://doi.org/10.19044/esj.2017.v13n13p272.

[20] N. H. Zardari, K. Ahmed, S. M. Shirazi, and Z. B. Yusop, *Weighting Methods and Their Effects on Multicriteria Decision-Making Model Outcomes in Water Resources Management*. Cham: Springer International Publishing, 2015. doi: https://doi.org/10.1007/978-3-319-12586-2.

[21] X. Wang and Q. Duan, "Improved AHP–TOPSIS Model for the Comprehensive Risk Evaluation of Oil and Gas Pipelines," *Petroleum Science*, vol. 16, no. 6, pp. 1479–1492, Sep. 2019, doi: https://doi.org/10.1007/s12182-019-00365-5.

[22] M. Eryiğit and S. O. Sulaiman, "Specifying Optimum Water Resources Based on Cost-benefit Relationship for Settlements by Artificial Immune Systems: Case Study of Rutba City, Iraq," *Water Supply*, vol. 22, no. 6, pp. 5873–5881, Jun. 2022, doi: https://doi.org/10.2166/ws.2022.227.

[23] M Eryiğit, S. O. Sulaiman, A. Najm, and Nebras Mahmood Mhedi, "Optimal Management of Multiple Water Resources by a Heuristic Optimization for a Water Supply in the Desert Cities of Western Iraq," *Desalination and Water Treatment*, vol. 281, pp. 7–14, Jan. 2023, doi: https://doi.org/10.5004/dwt.2023.28239.

[24] L. Oliver, "The AHP Method: Definition and Example," *Indeed Career Guide*, 2023. https://www.indeed.com/career-advice/career-development/ahp-method

[25] D. Romero-Faz and A. Camarero-Orive, "Risk Assessment of Critical Infrastructures – New Parameters for Commercial Ports," *International Journal of Critical Infrastructure Protection*, vol. 18, pp. 50–57, Sep. 2017, doi: https://doi.org/10.1016/j.ijcip.2017.07.001.

[26] A. M. Negm, *The Nile Delta*. Springer Nature, 2017. doi: https://doi.org/10.1007/978-3-319-56124-0.

[27] Wikipedia Contributors, "Western Desert," *Wikipedia*, Jul. 15, 2023. https://en.wikipedia.org/w/index.php?title=Western_Desert_(Egypt)&oldid=1165435981 (accessed 2024).