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# SWOT AND AHP-BASED ANALYSIS OF THE REALITY OF IRRIGATION PROJECTS' WATER CONVEYANCE SYSTEMS IN IRAQ

Zyad M. AL-JABAL[1,*], Mahmoud S. AL-KHAFAJI[2]

[1] Dept. of civil Engineering, Al-Nahrain University, Baghdad - Iraq.
[2] Dept. of Water Resources Engineering, University of Baghdad, Baghdad-Iraq.
[*]corresponding author: zeyad.mciv22@ced.nahrainuniv.edu.iq

**Abstract**

This study evaluates the main challenges facing open and closed water conveyance systems, where expert opinions vary. A SWOT-based questionnaire was conducted with 80 experts from diverse fields over three rounds. Two major irrigation projects—the Al Hussainiya Land Reclamation Project (HLRP) and the Abu Ghraib Irrigation Project (AGIP)—were selected as case studies. An Analytical Hierarchy Process (AHP) model was developed to identify and prioritize key decision-making criteria. Findings revealed major weaknesses, including high conveyance losses, delays in upgrading from unlined to lined or closed canals, lack of integrated maintenance planning, and shortage of specialized technical staff. These issues have led to neglect in many projects. The study highlights the importance of reducing losses and modernizing systems. Combining SWOT and AHP provides a structured, scientific basis for evaluating conveyance methods and generating practical recommendations for improving water resource management in semi-arid regions.

**Keywords:**

SWOT;
Water Resources;
Management;
AHP Method;
Decision Making;
Conveyance Efficiency.

## 1 Introduction

The water resources sector in Iraq faces major losses because more than 50% of the main and secondary canals are unlined [1]. This causes water loss through seepage and evaporation, especially in hot weather. There are also problems with water quota violations and a lack of skilled workers in irrigation projects. To solve these issues, a clear method is needed to choose the best water conveyance system.

This research compares open and closed systems using a decision-making framework based on SWOT and the Analytic Hierarchy Process (AHP). The AHP model helps rank key factors and choose the best system. Data was collected through expert surveys, case studies, and cost analysis. The goal is to compare construction, operation, and maintenance costs of each method.

AHP is a well-known method created by Saaty in the 1970s [3]. It is used in many fields like engineering, management, and environment. It has been used in dam site selection [5], flood mapping [6], and groundwater recharge planning [7]. Other studies used AHP with GIS for better results [63], [64]. This study focuses on combining both systems in one model, which is rarely done.

The SWOT-AHP method combines expert knowledge with numbers to rank issues. SWOT lists strengths, weaknesses, opportunities, and threats. AHP gives them weights and priorities. This makes the decision more reliable and scientific [2].

Many studies used AHP in water management. For example, [4] showed how AHP works with other methods like mathematical models. [5] applied AHP for choosing dam locations using both technical and social factors. [6] used AHP and GIS to find flood-risk areas in Tunisia. [7] used it to pick the best places to recharge groundwater using treated water. [63] improved AHP group decisions by adding principal component analysis. [64] applied AHP in urban water planning, showing how flexible it is.

This paper addresses a major gap—no study so far has compared open canals and pipes together while also considering long-term costs. The research gives a new method to help Iraq improve its water projects using expert input and science.

SWOT-AHP has been applied to prioritize groundwater management strategies in arid regions, demonstrating that combining both methods enhances decision-makers' ability to categorize the factors influencing water resource management strategies [65]. Sustainable urban water management strategies have also been evaluated using SWOT-AHP, showing that this combination provides a robust framework for managing conflicting objectives in water resource systems [66].

## 2 Method and Material

The correct way to make a decision begins with collecting information, after reviewing the related literatures and previous works, takes two paths, as shown in the Figure 1, data collection and studying projects design data. Site investigations were conducted, along with expert opinions, to compile a comprehensive database for conducting the questionnaire.

A number of irrigation projects were visited in Baghdad and Karbala governorates in Iraq (Figures 2 and 3).

The visited projects include projects for conveying water through open canals and closed pipes. Consequently, two projects, which are the Al Hussainiya Land Reclamation Project (HLRP) in Karbala and the Pioneering Abu Ghraib Irrigation Project (AGIP) in Baghdad. Observations were recorded regarding the obstacles facing work and water conveyance for the purpose of presenting them to the group of experts.

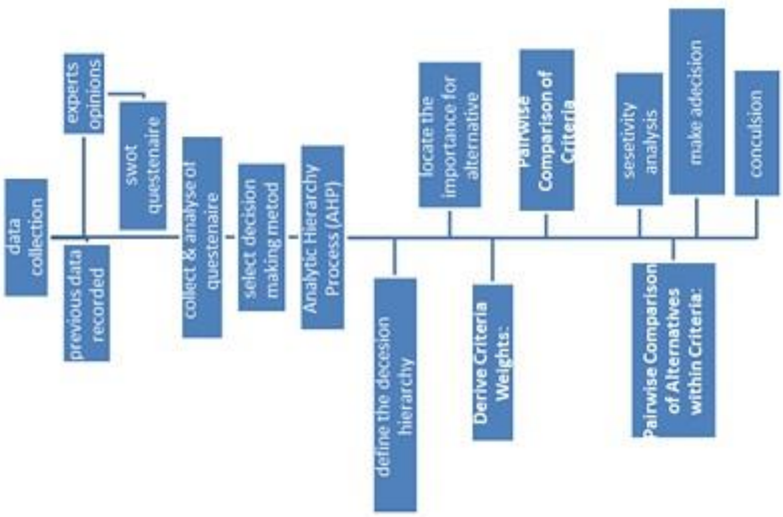


Fig. 1: Methodology diagram.

### 2.1 Study Area

According to the technical and economic feasibility study published by Ministry of Planning of Iraq (M.O.P), the area of arable lands in Iraq is 13,487,700 donums (1 dunum = 0.1 hectare). These lands are cultivated either through irrigation, perpetual irrigation, or through groundwater [10]. Two-thirds of these area of cultivated land in Iraq are irrigated (Map 1). 63% of the irrigated lands are irrigated through gravity canals, while 36% of the lands receive irrigation water through pumps from main rivers or canals, and 1% is irrigated with groundwater from springs or pumped from aquifers [8].

Fig. 2: Site investigations.

Medium and large irrigation projects exist along Iraq's rivers including many irrigation canals and pumping systems.

Major irrigation projects in the country include the Al-Jazeera Irrigation Project in Nineveh Governorate, which draws water directly from the Tigris Reservoir and Mosul Dam and irrigate more than one million donums of land when fully developed; Kirkuk-Al-Atheem-Hawija Irrigation Project with more than one million donums of irrigated land, drawing water from various tributaries of the Tigris River, including the Little Zab; The Central Tigris Project, which covers more than 1.5 million donums on both sides of the Tigris River between Baghdad and Kut The Great Abu Ghraib Project, which is considered the largest irrigation project along the Euphrates River to irrigate more than 500 thousand donums between Fallujah and Baghdad Al-Ansari and [9].

According to [11] the total length of main, distributary, secondary and collector canals is 7463, 10737, 9551, 14773 (km) respectively. Across the country, irrigation infrastructure is largely old and damaged, including two pumping stations, built in the 1970s, and other canals that have not been adequately maintained since then [8] in 2015 study of 50,000 kilometers of irrigation canals found that only about 20% of the canals were lined with concrete, leading to significant water losses [1].

To select a case study covers the variety requirements from type of system (open and closed) and operation period, as well as the area extant and location, all the studies of irrigation projects in Iraq were reviewed. Preliminary, some projects were selected in Baghdad and Karbala governorates in Iraq and visited to take a closer look at the status of these projects (Figure 2). Consequently, two projects, which are the Pioneering Abu Ghraib Irrigation Project (AGIP) in Baghdad and Al Hussainiya Land Reclamation Project (HLRP) in Karbala were selected to be the case studies. Observations were recorded regarding the obstacles facing work and water conveyance for the purpose of presenting them to the group of experts.

Table 1: Irrigation network of the HLRP [13].

| Main canal | No. of Distributary pipes conduits | Type | Length of Main Canal [m] |
|---|---|---|---|
| DC1/MC | 4 | Lined canal | 650 |
| DC3/MC | 5 | Lined canal | 940 |
| DC5/MC | 5 | Ductile Pipe | 400 |
| DC7/MC | 3 | Ductile Pipe | 518 |
| DC9/MC | 7 | Lined canal | 1000 |
| DC11/MC | 5 | Lined canal | 2300 |
| DC13/MC | 2 | Lined canal | 1144 |
| DC13-2/MC | 7 | Lined canal | 1725 |
| DC13-3/MC | 2 | Lined canal | 600 |

### 2.1.1 Hussainiya Land Reclamation Project (HLRP)

HLRP is one of the recent projects that began operation in Karbala Governorate, it includes six stages with a total area of one hundred thousand donums extending over the provinces of Karbala and Babylon. Parts of the fourth stages on a rights bank of AL-Hussainiya River and the entire area of the first stage, estimated 15,000 donums, have been implemented. The construction and operation of first stage of the project started 2019 and 2022, respectively. The area of first stage is 10000 donums (Figure 3).

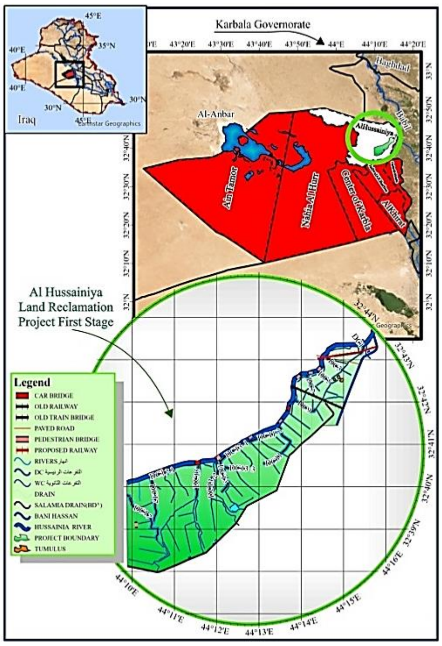


Fig. 3: Location and layout of HLRP, based on [12].

The water conveyance and irrigation network of the project includes main open canals of 8500 m and 1000 m main pipe conduits length respectively. The project consists of 9 main canals (Table 1), 7 of which are lined

open canal and 2are closed conduits (ductile pipes) with diameters of 700 and 800 mm, [12]. The irrigation network (distributary conduits) are P.V.C. pipes of different diameters (250mm to 500mm). The total length of irrigation pipes is approximately 34,000 m, and discharges ranging from 19-70 l/s.

In addition to other hydraulic structures such as roads crossing structures and drainage network and drainage structures. Actual operation of the project began in mid-2022.

### 2.1.2 Pioneering Abu Ghraib Irrigation Project (AGIP)

Pioneering Abu Ghraib Irrigation Project (AGIP) is one of the oldest and important irrigation projects in Iraq. The construction works of this project were started in 1931. It was officially opened in April 1936. The construction continued for several years until 1979 [14]. In 2018, the development and reclamation continued by constructed closed conduits with pumping stations by Iraq company for irrigations projects (ICIP) in 2021 to 2023 [15].

This project is located in the southwestern part of Baghdad City (Abu Ghraib District) Figure 4, bordered to the north by the Saqlawiyah Irrigation Project and the land of Fallujah District. From the south, it is bounded by the Radwaniya Irrigation Project. The northern part of Main Outfall Drain (MOD) is extended to the east of the project and from the west the lands of Fallujah Project confined between the right of Almuahada Canal and Euphrates River [14].

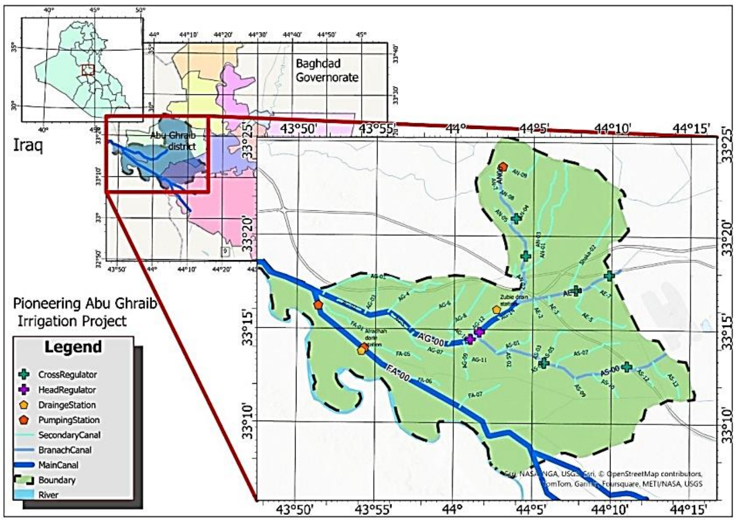


Fig. 4: Location and layout of AGIP.

The newly constructed closed canals in the project serves 7000 dunums of agricultural land using modern irrigation methods. There is three pumping stations in the project. Each pumping station in the project consists of 5 vertical pumps with a discharge of 280 l/s, [15]. In view of the statute of limitations of hydraulic facilities and the occurrence of disappearances in their parts due to the neglect of maintenance work (Table 2), the cost of maintenance in recent years has become a burden on the annual budget.

In terms of maintenance costs, variance is noticed due to lack of an integrated administrative plan for maintenance of the project. Table (2) describes maintenance costs for Abu Ghraib project from 2018 to 2022 [15]. It is clear that the maintenance costs are very high, especially since the canals have been built for more than 40 years, and the maintenance costs have exceeded the construction costs. This required the concerned authorities to establish closed canals, which began operating recently in the sixth month of 2023.

Table 2: Maintenance costs for Abu Ghraib project from 2018 to 2022 [15].

| Item | 2018 | 2019 | 2020 | 2021 | 2022 | Total | Items | Items [%] |
|---|---|---|---|---|---|---|---|---|
| Repairing the crack | 0 | 0 | 0 | 433667500 | 414835800 | 848503300 | 433667500 | 44.0 |
| Treatment of corrosion | 0 | 0 | 0 | 0 | 906144360 | 906144360 | 0 | 47.0 |
| Open and Sizing outlet | 8860500 | 0 | 0 | 0 | 0 | 8860500 | 0 | 0.5 |
| Smoothing Section | 0 | 0 | 0 | 150410400 | 0 | 150410400 | 150410400 | 7.8 |
| lining Works | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 |
| Cleansing works | 187987.5 | 174099 | 105044 | 0 | 467130.5 | 467130.5 | 0 | 0.02 |
| Total | | | | | | 1,914,385,691 | | 100 |

## 2.2 Conveyance Efficiency

It measures how effectively the system conveyance water, accounting for losses due to factors like seepage, evaporation, or leakage along the route [16].

$$E_C = (Q_2/Q_1) * 100 \tag{1}$$

where:
$E_C$ - the conveyance efficiency of the mechanism.
$Q_1$ - the quantity of water per time enter the network.
$Q_2$ - the amount of water per time leave the network.

### 2.2.1 Theoretical Efficiency

The efficiency is obtained by conducting the losses by empirical equations. If the canals are lined with concrete, the losses are limited mainly from evaporation losses and seepage losses[16] and [17].

For seepage losses and lined canals [18] and [62] the equation is:

$$Qs = Ks \cdot L \cdot (hu - hd) \tag{2}$$

Where Qs is the seepage loss (volume per unit time), Ks is the seepage coefficient, representing the hydraulic conductivity of the lining material (units of length per unit time), L is the length of the canal, hu is the upstream water level (head),hd is the downstream water level (head).

(Ks) depends on the properties of the lining material, such as its permeability. It can be determined through laboratory testing or field measurements. but it is typically on the order $10^{-9}$ to $10^{-11}$ m/s [19].

For evaporation losses, obtained from Eq. (3) [20] as follows:

$$R = \frac{E\times W\times L}{Q} x100 \tag{3}$$

where:
*R* - is the evaporation loss.
*E* - is the rate of evaporation [m /day].
*W* - is the water surface breadth in the canal [m].
*Q* - is discharge rate [m³/day].

The theoretical efficiency can be conducted from

$$E_{th} = Q_{out} - Q_S - R \tag{4}$$

### 2.3 SWOT Analysis

A SWOT analysis is a commonly used modern scientific method by organizations and companies to identify internal factors such as strengths and weaknesses, as well as external factors like opportunities and threats. To improve the analysis, other methods and theories, such as the Delphi Technique (DT) and Porter's Five Forces, are often employed, as seen in [21], [22], and [23].

These methods support decision-making by facilitating idea exchange and brainstorming [24]. DT is commonly integrated into SWOT analysis [25], as demonstrated by previous studies conducted by [26] and [27]. It is straightforward to use, as it does not require complex mathematical models for implementation and analysis. Additionally, the anonymity it provides enables experts to freely share their opinions without the influence of external biases. DT is often coupled with the Likert Scale, a tool with multiple options that allows experts to express their views more clearly [28]. Various techniques can be employed to analyse, compare, and present results effectively

### 2.3.1 Questionnaire Component

In this research, a Five-points Likert Scale (Figure 5) was chosen because of its ease of answering and lack of complexity. The development of water resources in Iraq through open and closed conveyance systems was chosen as a goal to be achieved through this questionnaire. Several factors led to the selection of a group of experts, including practical experience, precise specialization, and current work.

| Strongly disagree | Disagree | Neutral | Agree | Strongly agree |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

Fig. 5: The Five-points Likert Scale of SWOT questionnaire.

SWOT analysis is conducted with the following steps:

### A. Composition and panel size

Eighty individuals who combine experience, competence and diversity in various fields related to water resources were selected by engineers from the Ministry of Water Resources in all its formations and the Ministry of Higher Education and Scientific Research, including professors and researchers, in addition to a number of site engineers and farmers who are in contact with the problems to be solved. The experts are divided according to each person's academic degree, their place of work in the institutions, and their practical specialization.

### B. Collect and analyze expert opinions

In this step, the questionnaire is distributed and the opinions dictated by the experts are collected. This step is done electronically or submitted on paper.

### C. First questionnaire

At this stage, the questionnaire is open to take the opinions of experts and enrich the SWOT elements. Ask them whether this represents one of the elements of SWOT, and the answer is (1): yes or (2): no, through using the questioner form shown in Table 4.

Table 3: A sample form of the 2nd round of questionnaire.

| sequence | Issue | SWOT Elements | A B C |
|---|---|---|---|
| 1 | Details | Details | No. |
| 2 | Details | | |
| 3 | Details | | |
| N | Details | | |

Table 4:1ST round Questionnaire form.

| sequence | Issue as part of SWOT | Do you agree with experts that these elements represent SWOT |
|---|---|---|
| 1 | Details | Yes No |
| 2 | Details | Yes No |
| 3 | Details | |
| n | Details | |

### D. Second questionnaire

The questionnaire at this stage is closed and consists of questions that include main criteria for reaching the goal (Table 3). There are alternatives and factors that must be evaluated by experts to reach this goal. It is divided into the main SWOT elements of strength, weakness, available opportunities, and future threats. The answers are according to the five-point Likert Scale, and the answer represents (1 and 2), group A of answers means acceptance of this proposition, Group B represents the intermediate state between acceptance and rejection, while Group C of answers (4 and 5) represents rejection of this proposition. These steps were taken based on the methodology published in [29].

### E. Third questionnaire

At this stage of the questionnaire (Table 5), reliance is placed on the results of the second stage by giving each element of the SWOT an importance ranging from (1, 3, 5,7and 9) based on the methodology mentioned in [30].

Table 5: Questionnaire form for importance of each element in SWOT compared to other elements.

| Issue | Sequence | SWOT Elements | Degree of Important |
|---|---|---|---|
| Management and use of water resources | 1 | Details | 1, 3, 5, 7, 9 |
| | 2 | | |
| | 3 | | |
| | n | | |

After completing the site investigations and taking the opinions of those concerned, each of the SWOT standards was divided into three sub-standards due to the centrality of the dilemmas and solutions into three sections: Government control and management, Human resources and use of water resources and finally, cost of construction and maintenance, each SWOT elements contains 3 main criteria and a number of secondary criteria, as shown:

**C1: Government control and management:**

The government has a role in monitoring the rate of pollution and violations of water conveyance canals, developing solutions and agreements with neighboring countries, and legislating new projects to increase water efficiency.

**C2: Human resources and use of water resources:**

It includes controls on water use by farmers, not exceeding water quotas, and increasing the operational and scientific capacity of the specialized scientific staff of technicians and operators.

**C3: Cost of construction and maintenance:**

The most important factor facing the implementation of projects is providing financial allocations, as well as following the correct methods in maintenance work to avoid the deprecation of the implemented projects.

### 2.4 AHP Analysis

Using the AHP Method with SWOT analysis requires a number of steps, as illustrated in Figure 6 and explained below:

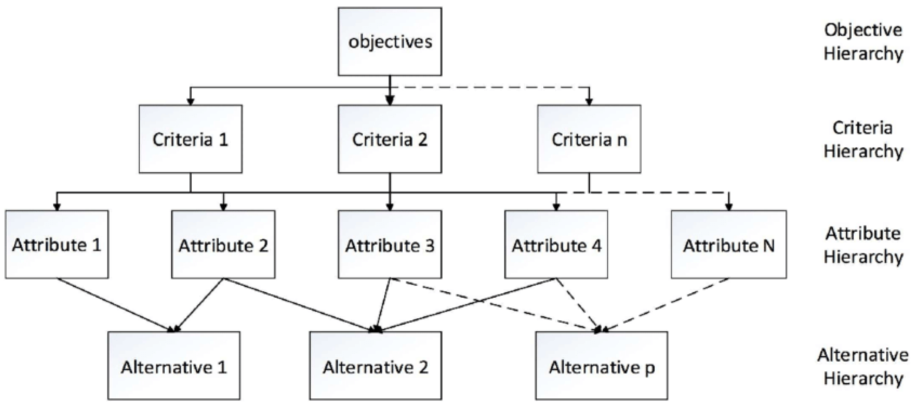


Fig. 6: A scheme of hierarchical structure of an MADM problem [31].

i. Define Criteria and Sub-Criteria: Identify the criteria and sub-criteria relevant to main goal (figure 6), (For more detail see [32].

ii. Pairwise Comparison: Within each SWOT category (Strengths, Weaknesses, Opportunities, Threats), conduct pairwise comparisons using the AHP method. Each strength is compared against the others to determine its relative significance, and this process is repeated for weaknesses, opportunities, and threats.

Let A = $\{a_1, a_2, \ldots, a_m\}$ represent the set of possible alternatives (a). Similarly, C = $\{c_1, c_2, \ldots, c_n\}$ refers to the set of pre-defined evaluation criteria (c).

The pairwise comparison matrix serves as the tool through which the AHP method derives the preference value for each item set concerning a particular aspect of the decision. Let P represent the pairwise comparison matrix, which can be expressed as follows [33]:

$$P = \begin{matrix} \boldsymbol{a_1} \\ \boldsymbol{a_m} \end{matrix} \begin{bmatrix} \boldsymbol{P}_{(\mathbf{1},\mathbf{1})} & \cdots & \boldsymbol{P}_{(\mathbf{1},\boldsymbol{M})} \\ \vdots & \ddots & \vdots \\ \boldsymbol{P}_{(\boldsymbol{M},\mathbf{1})} & \cdots & \boldsymbol{P}_{(\boldsymbol{M},\boldsymbol{M})} \end{bmatrix} \boldsymbol{P}_{(\boldsymbol{i},\boldsymbol{i})=\mathbf{1}} \tag{5}$$

Where p(i,j) represents the pairwise comparison between the iii-th and jjj-th alternatives, the matrix PPP serves as the pairwise comparison matrix for the feasible alternatives, constructed based on the implicit scales determined by the decision-maker. Therefore, the elements within the matrix can be utilized to calculate the preference value for each alternative. In essence, the relative values of the matrix elements are expressed as follows [34]:

$$p(i,j) \; = \; vi \; / \; vj \tag{6}$$

in which $\mathrm{vi}$ and $\mathrm{vj}$ = the absolute preference value of the ith and jth alternatives, respectively. Logic dictates that any pairwise comparison matrix must satisfy the following property, better known as the reciprocal property [36]:

$$\mathrm{p(i,j)} \; = \; 1 \; / \; \mathrm{p(j,i)} \tag{7}$$

iii. Assign Weightings: Assign weights to each criterion and sub-criterion as in Table 7 based on the results of the pairwise comparisons. These weights represent the relative importance [35] of each factor in contributing to the overall objective.

Table 6: A typical pairwise comparison scale for the AHP method (Based on [37]).

| Intensity of decision-maker's | Definition |
|---|---|
| 1 | Equally important |
| 3 | Moderate |
| 5 | Strong |
| 7 | Very strong |
| 9 | Extreme |
| 2,4,8 | Intermediate values between the two adjacent judgments |

Based on Ebert and Welsch (2004) the pairwise comparison matrix introduced in Eq. (8) is revised as follows:

$$P = \begin{matrix} a_1 \\ a_m \end{matrix} \begin{bmatrix} v_{1/v1} & \cdots & v_{1/v_m} \\ \vdots & \ddots & \vdots \\ v_{m/v_1} & \cdots & v_{m/v_m} \end{bmatrix} \tag{8}$$

The decision-maker derives a preference weight vector, denoted by $\mathrm{W} \; = \; (\mathrm{v1}, \mathrm{v2}, \ldots, \mathrm{vi}, \ldots, \mathrm{vm})$, where $\mathrm{vi}$ represents the normalized preference value of the $\mathrm{ith}$ alternative. Mathematically, it can be written as followed [38].

$$\begin{bmatrix} v_{1/v1} & \cdots & v_{1/v_m} \\ \vdots & \ddots & \vdots \\ v_{m/v_1} & \cdots & v_{m/v_m} \end{bmatrix} \times \begin{bmatrix} V_1 \\ V_m \end{bmatrix} = M \times \begin{bmatrix} V_1 \\ V_M \end{bmatrix} \tag{9}$$

Equation (9) implies the result of multiplying the pairwise comparison matrix P by the weights vector W = $(\mathrm{v_1},\ \mathrm{v_2},\ \ldots,\ \mathrm{v_i},\ \ldots,\ \mathrm{v_m})^{\mathrm{T}}$ yields a result equal to m, which is the number of alternatives multiplied by the weight vector [40]. Here, m represents the eigenvalue of the pairwise comparison matrix P, and W is the corresponding eigenvector. The sum of the eigenvalues of a matrix is equivalent to its trace, which is the sum of its diagonal elements. In this case, the trace of the pairwise comparison matrix P equals m. Hence, m is the largest or principal eigenvalue of P. Solving P×W=m×W yields the principal right eigenvector of P, which consists of positive entries and is unique up to a multiplicative constant [39].

iv. Check Consistency (optional): Finally, check the consistency of your comparisons using a consistency ratio (CR) [41].

## 3. Results and Discussions

### 3.1 Conveyance Efficiency of Canals

The theoretical efficiency is obtained using Equation 4 after applying all the data as in the Table below.

Table 7: Theoretical efficiency of (HLRP) canals.

| Canal | V Theoretical [m/s] | $Q_{Theoretical}$ $[m^3/s]$ | $Q_{Seepage}$ $[m^3/s]$ | Average Evaporation Rate [mm] | Width of Water Surface [m] | Length [m] | Rate of Evaporation loss (unit less) | Total losses [%] | $Q_{Final}$ $[m^3/s]$ | Efficiency [%] |
|---|---|---|---|---|---|---|---|---|---|---|
| DC1 | 0.32 | 0.103 | $2.21\times 10^{-13}$ | 234.5 | 2.6 | 650 | 0.035 | 3.56 | 0.099 | 96.44 |
| DC3 | 0.35 | 0.142 | $3.54\times 10^{-12}$ | 234.5 | 2.75 | 940 | 0.038 | 3.89 | 0.136 | 96.11 |
| DC5 | 0.33 | 0.1 | | 234.5 | | 400 | | | | 100 |
| DC7 | 0.29 | 0.053 | | 234.5 | | 518 | | | | 100 |
| DC9 | 0.4 | 0.24 | $6.42\times 10^{-12}$ | 234.5 | 3.15 | 1000 | 0.028 | 2.85 | 0.235 | 97.85 |
| DC11 | 0.46 | 0.435 | $5.12\times 10^{-12}$ | 234.5 | 3.4 | 2300 | 0.039 | 3.91 | 0.417 | 96.09 |
| DC13 | 0.49 | 0.554 | $7.53\times 10^{-12}$ | 234.5 | 3.6 | 1144 | 0.016 | 1.62 | 0.545 | 98.38 |

The second and third columns above represent the values taken from Ministry of Water Resources in Iraq (MoWR), while the fourth column is the result of applying equation (2). The fifth one is the annual evaporation rate for the Iraqi weather taken from Iraqi General Authority for Meteorology and Seismic Monitoring (GAMS) on its official website. As for the sixth column, it represents the width of the canal section from above. The seventh column is the length of the canal, as shown in Table 1. The eighth column is the result of applying equation (3), while the ninth column It is the result of converting the previous column into a percentage of the theoretical quantity by equating the units of volume and time and dividing them by the theoretical discharge in column No.3 and convert it to a percentage. The tenth column is the result of applying equation (4). Finally, the last column is the result of subtracting 100% from the total losses to get the theoretical efficiency.

Lining irrigation canals is regarded as one of the most effective methods for minimizing water losses in conveyance systems under optimal conditions [18]. Canal lining enhances flow efficiency, significantly reduces seepage losses, inhibits weed growth, and lowers maintenance expenses. Furthermore, it helps prevent waterlogging in nearby low-lying agricultural areas [43]. Different lining materials reduce seepage loss, including compacted earth, concrete, flexible membranes, asphaltic concrete, and soil cement mixtures [44].Therefore, when applying equation 2. the resulting amount of annual losses is small when comparing to evaporation losses, and this is what was mentioned in [18] While evaporation losses are considered effective, and the evaporation rates were obtained from periodic bulletins published by General Authority for Meteorology and Seismic Monitoring (GAMS) on its official website, where it has two measuring stations in the regions of Al-Razzaza and Ain Al-Tamr [42]. The theoretical efficiency of ductile Iron Pipes (DIP) in water conveyance systems is often regarded as near 100% due to their smooth internal surface, which minimizes hydraulic resistance, and their robust structural integrity that prevents leaks [45].

The Actual efficiency obtained based on data of [13] and the discharge of each distributary canals within the main canals. The efficiency was calculated (Table 8) at the end of each canal according to what stated in [46] and equation (1).

Table 8: Actual Efficiency for (HLRP) canals and conduits.

| Main canal | Q1 [l/s] | Q2 [l/s] | Actual Efficiency [%] |
|---|---|---|---|
| DC1/MC | 50 | 46.17 | 92.33 |
| DC3/MC | 69 | 65.69 | 95.2 |
| DC5/MC | 54 | 53.68 | 99.4 |
| DC7/MC | 26 | 25.86 | 99.48 |
| DC9/MC | 120 | 115.09 | 95.91 |
| DC11/MC | 118.5 | 91.30 | 77.05 |
| DC13/MC | 127 | 109.07 | 85.88 |
| DC13-2/MC | 110 | 98.18 | 89.25 |

Fig. 7: The violations observed on sedimentation basin of DC 11 canal.

The above results (Table 8) conducted from site investigations and evidence of General Authority for Operation of Irrigation Projects in Iraq with applied of equation (1) are considered acceptable according to what was stated in [47] which states that conveyance efficiency is considered acceptable if it is between 80-90% and is considered highly efficient if it is more, with the exception of canal (DC 11), which had low conveyance efficiency. It is considered the longest canal, which increases evaporation losses as in [48] due to the violations that were monitored (Figure 7) and the length of its path compared to the rest. This results when compared with what is illustrated in according to [49] containing open canals in India, have an different efficiency, primarily due to water loss through evaporation, seepage, and operational spillages.

On the other hand, closed conduit systems, such as pipes, demonstrate an efficiency ranging from 80-90% as in [50] conducted in Spain; [51] carried out in Portugal.These higher efficiencies in closed systems result from reduced water loss and more precise control over water distribution.

Such findings highlight the potential benefits of transitioning from open to closed systems for enhanced water use efficiency in irrigation practices. As shown below. The efficiency of conveyance of the canals is due to the modernity of the canal’s construction, the efficiency of the accompanying technical staff in removing violations, preserving water quotas, and the effectiveness of the subsidiary canal gates. Therefore, it is more useful to calculate the amount of water lost and its cost, as shown in the (Table 9) and Figure 8.

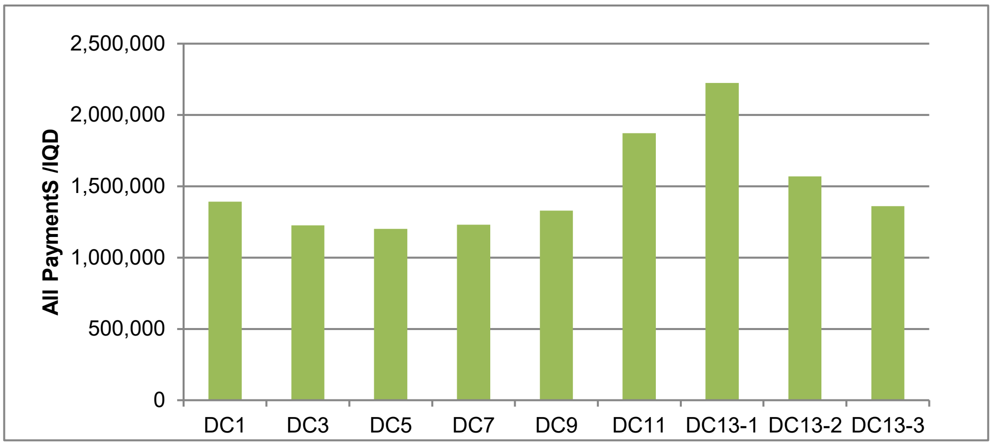


Fig. 8: All payments /IQD.

Table 9: Payments of (HLRP) after10 years of operation.

| Main canal | Maintenance Cost for 10 yrs. (IQD/M.L) | Operation cost For 10 yrs. (IQD/M.L) | Losses Cost For 10 yrs. (IQD/M.L) | Value of canal/M.L After 10 yrs. (IQD) | All payments Values after 10 years Of Operation (IQD) |
|---|---|---|---|---|---|
| DC1/MC | 230,800 | 650,797 | 458,783 | 52,801 | 1,393,181 |
| DC3/MC | 230,800 | 650,797 | 273,979 | 70,504 | 1,226,080 |
| DC5/MC | 40,000 | 650,577 | 62,985 | 447,202 | 1,200,764 |
| DC7/MC | 40,000 | 650,577 | 20,295 | 520,643 | 1,230,938 |
| DC9/MC | 230,800 | 650,797 | 381,646 | 66,287 | 1,329,530 |
| DC11/MC | 230,800 | 650,797 | 919,452 | 71,763 | 1,872,812 |
| DC13/MC | 230,800 | 650,797 | 1,218,901 | 125,044 | 2,225,542 |
| DC13-2/MC | 230,800 | 650,797 | 533,298 | 154,270 | 1,570,000 |
| DC13-3/MC | 230,800 | 650,797 | 386,713 | 93,333 | 1,361,643 |

The data of construction, maintenance and operation costs, listed in Table 9, was collected from the project construction and operation documents [13]and site investigations Although the costs of constructing closed conduits (pipes) for the DC 7 and DC5, are much more than other open canals, it appears that these costs and losses in conveyance are very high, which leads to an increase in the total cost for the first ten years of operation.

### 3.2 Analysis of Panel and Experts' Information

The qualifications, specializations, academic degrees, workplace affiliations, and years of experience of the expert sample (comprised of 80 individuals) are depicted in Figure 9. This figure illustrates that a significant proportion of the experts possess a bachelor's degree. Furthermore, Figure 10 highlights the distribution of the experts' general fields of specialization. The majority of the panel consists of civil engineers (42%), followed by those specializing in water resources (23%), environmental engineering (12%), middle school graduates (9%), and agricultural specialists (8%). These represent the key fields integral to water resources management. Notably, the representation of farmers is lower than expected despite their crucial role in various aspects related to water management.

From Figure 10, it is apparent that although civil engineering forms the bulk of the general specialization, subspecialties critical to the design, maintenance, and operation of water resource infrastructures, such as sanitary engineering and water quality management, are underrepresented. Environmental engineering maintains its expected share, followed closely by water resources engineering.

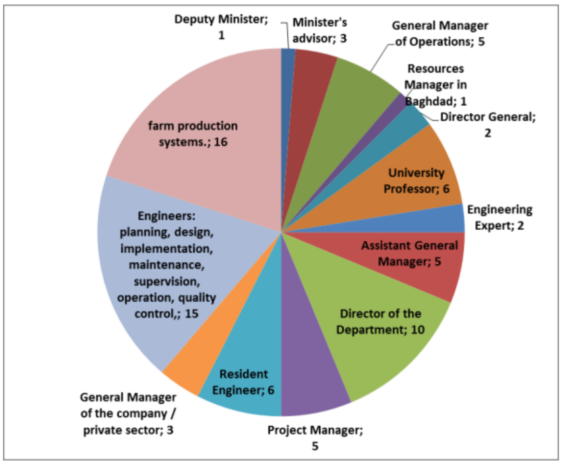


Fig. 9: Scientific Degree of Experts.

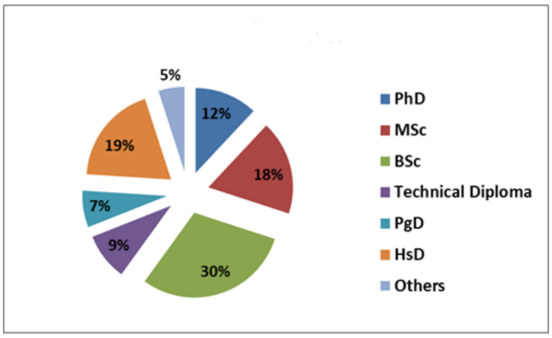


Fig. 10: General specialization portion.

The diverse affiliations of the experts are represented in Figure 11. Participants include professors and lecturers from higher education institutions, designers from the Ministry of Water Resources, and professionals with varying lengths ofservice, from as little as one year to over 40 years. The sample encompasses experts from various Iraqi governorates, though the Ministry of Water Resources had the most significant representation, given its relevance to this study. Additionally, experts held a range of positions, including undersecretaries, consultants, department heads, designers, maintenance planners, and project managers, all contributing to the operational and management processes, as illustrated in Figure 11.

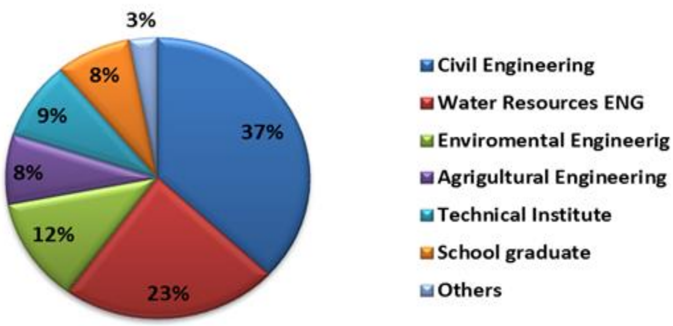


Fig. 11: Administrative position of the Experience.

### 3.3 Results of Questionnaires Rounds

The questionnaire was conducted in three stages, as described in the methodology. The first stage was to select 80 experts and take their opinions on the topics and criteria to be taken into consideration. The second stage was to ask specific questions, the answers to which would be according to the Likert Scale. As for the third stage, every major and secondary criterion was given an importance that was between (1 to 9) and according to the opinions of the above experts as illustrated in Figure 12, the result was as follows:

It is clear that the greatest weight is given to threats and weaknesses, as each of them received an impact of 7, according to the opinions of experts, because their influence factors gradually increase with increasing risks, especially with the lack of treatment by the administration and the large number of climate challenges and water scarcity.

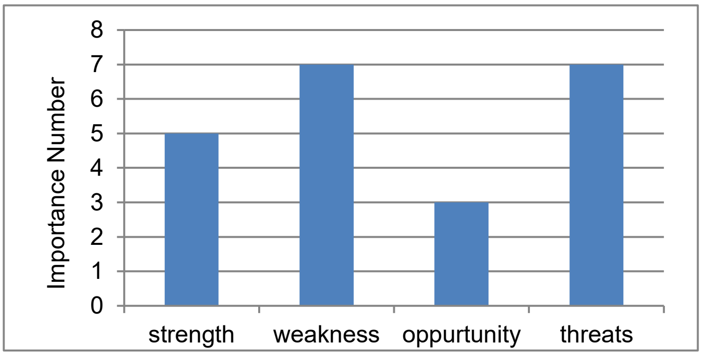

Fig. 12: SWOT elements importance.

A. Define criteria of each SWOT elements:

Based on the opinions of experts, three main criteria were identified for each of the SWOT elements, given the consensus of experts that these standards include the most important problematic issues facing water conveyance projects in Iraq.

C1: Government control and management.
C2: Human resources and use of water resources
C3: Cost of construction and maintenance

Each major and minor criteria items is given a factor of importance according to the opinions of the experts in the third round of the questionnaire, where (80) opinions in this field were filtered and the weights that were unanimously obtained were taken and then returned again to the experts to present the opinions in which there was disagreement in order to come up with a unified result.

B. Pairwise comparison matrix

Given the sub-criteria with their importance values (converted to decimal) then Normalized Pairwise Comparison Matrix for Sub-Criteria by Sum each column of sub criteria matrix then normalize it by dividing each element by the column sum. After that, get the Average of each row to conclude the priority vector for sub-criteria. So, the recalculated priority vectors considering the corrected importance values are now represented in a decimal format for clarity. Finally, combine the weights of the main criteria with the weights of their respective sub-criteria to get the final weights as in tables below:

Based on equations (4, 8, and 9) and expert's opinions with importance weight in three stages of questionnaire for SWOT elements with sub criteria (C1, C2 and C3) as presented in Tables below:

A. Strength Element

The main criteria are:

C1: Government control and management (Importance = 3)
C2: Human resources and use of water resources (Importance = 5)
C3: Cost of construction & maintenance (Importance = 7)

**Step 2: pairwise comparison matrix based on these importance values.**

Table 10: Main Criteria Pairwise Comparison Matrix.

| | C1 | C2 | C3 |
|---|---|---|---|
| C1 | 1.000 | 0.600 | 0.429 |
| C2 | 1.667 | 1.000 | 0.714 |
| C3 | 2.333 | 1.400 | 1.000 |

**Step 3: Normalization of the Main Criteria Pairwise Matrix**

To normalize the matrix, sum the values in each column and then divide each element by the sum of its column. The column sums are calculated as follows:

Table 11: Normalized Main Criteria Pairwise Matrix of strength element.

| | C1 | C2 | C3 |
|---|---|---|---|
| C1 | 1.000/5.000 = 0.200 | 0.600/3.000 = 0.200 | 0.429/2.143 = 0.200 |
| C2 | 1.667/5.000 = 0.333 | 1.000/3.000 = 0.333 | 0.714/2.143 = 0.333 |
| C3 | 2.333/5.000 = 0.467 | 1.400/3.000 = 0.467 | 1.000/2.143 = 0.467 |

**Step 4: Pairwise Comparison of Sub-Criteria for C1: Government Control and Management**

Table 12: Pairwise Comparison of Sub-Criteria for C1.

| | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | S10 |
|---|---|---|---|---|---|---|---|---|---|---|
| S1 | 1.000 | 3.000 | 0.600 | 0.600 | 0.600 | 1.000 | 1.000 | 3.000 | 1.000 | 0.600 |
| S2 | 0.333 | 1.000 | 0.200 | 0.200 | 0.200 | 0.333 | 0.333 | 1.000 | 0.333 | 0.200 |
| S3 | 1.667 | 5.000 | 1.000 | 1.000 | 1.000 | 1.667 | 1.667 | 5.000 | 1.667 | 1.000 |
| S4 | 1.667 | 5.000 | 1.000 | 1.000 | 1.000 | 1.667 | 1.667 | 5.000 | 1.667 | 1.000 |
| S5 | 1.667 | 5.000 | 1.000 | 1.000 | 1.000 | 1.667 | 1.667 | 5.000 | 1.667 | 1.000 |
| S6 | 1.000 | 3.000 | 0.600 | 0.600 | 0.600 | 1.000 | 1.000 | 3.000 | 1.000 | 0.600 |
| S7 | 1.000 | 3.000 | 0.600 | 0.600 | 0.600 | 1.000 | 1.000 | 3.000 | 1.000 | 0.600 |
| S8 | 0.333 | 1.000 | 0.200 | 0.200 | 0.200 | 0.333 | 0.333 | 1.000 | 0.333 | 0.200 |
| S9 | 1.000 | 3.000 | 0.600 | 0.600 | 0.600 | 1.000 | 1.000 | 3.000 | 1.000 | 0.600 |
| S10 | 1.667 | 5.000 | 1.000 | 1.000 | 1.000 | 1.667 | 1.667 | 5.000 | 1.667 | 1.000 |

Table 13: normalized matrix of C1.

| | S1 11.334 | S2 33.000 | S3 6.800 | S4 6.800 | S5 6.800 | S6 11.334 | S7 11.334 | S8 33.000 | S9 11.334 | S10 6.800 |
|---|---|---|---|---|---|---|---|---|---|---|
| S1 | 1.000/11.334 = 0.088 | 3.000/33.000 = 0.091 | 0.600/6.800 = 0.088 | 0.600/6.800 = 0.088 | 0.600/6.800 = 0.088 | 1.000/11.334 = 0.088 | 1.000/11.334 = 0.088 | 3.000/33.000 = 0.091 | 1.000/11.334 = 0.088 | 0.600/6.800 = 0.088 |
| S2 | 0.333/11.334 = 0.029 | 1.000/33.000 = 0.030 | 0.200/6.800 = 0.029 | 0.200/6.800 = 0.029 | 0.200/6.800 = 0.029 | 0.333/11.334 = 0.029 | 0.333/11.334 = 0.029 | 1.000/33.000 = 0.030 | 0.333/11.334 = 0.029 | 0.200/6.800 = 0.029 |
| S3 | 1.667/11.334 = 0.147 | 5.000/33.000 = 0.152 | 1.000/6.800 = 0.147 | 1.000/6.800 = 0.147 | 1.000/6.800 = 0.147 | 1.667/11.334 = 0.147 | 1.667/11.334 = 0.147 | 5.000/33.000 = 0.152 | 1.667/11.334 = 0.147 | 1.000/6.800 = 0.147 |
| S4 | 1.667/11.334 = 0.147 | 5.000/33.000 = 0.152 | 1.000/6.800 = 0.147 | 1.000/6.800 = 0.147 | 1.000/6.800 = 0.147 | 1.667/11.334 = 0.147 | 1.667/11.334 = 0.147 | 5.000/33.000 = 0.152 | 1.667/11.334 = 0.147 | 1.000/6.800 = 0.147 |
| S5 | 1.667/11.334 = 0.147 | 5.000/33.000 = 0.152 | 1.000/6.800 = 0.147 | 1.000/6.800 = 0.147 | 1.000/6.800 = 0.147 | 1.667/11.334 = 0.147 | 1.667/11.334 = 0.147 | 5.000/33.000 = 0.152 | 1.667/11.334 = 0.147 | 1.000/6.800 = 0.147 |
| S6 | 1.000/11.334 = 0.088 | 3.000/33.000 = 0.091 | 0.600/6.800 = 0.088 | 0.600/6.800 = 0.088 | 0.600/6.800 = 0.088 | 1.000/11.334 = 0.088 | 1.000/11.334 = 0.088 | 3.000/33.000 = 0.091 | 1.000/11.334 = 0.088 | 0.600/6.800 = 0.088 |
| S7 | 1.000/11.334 = 0.088 | 3.000/33.000 = 0.091 | 0.600/6.800 = 0.088 | 0.600/6.800 = 0.088 | 0.600/6.800 = 0.088 | 1.000/11.334 = 0.088 | 1.000/11.334 = 0.088 | 3.000/33.000 = 0.091 | 1.000/11.334 = 0.088 | 0.600/6.800 = 0.088 |
| S8 | 0.333/11.334 = 0.029 | 1.000/33.000 = 0.030 | 0.200/6.800 = 0.029 | 0.200/6.800 = 0.029 | 0.200/6.800 = 0.029 | 0.333/11.334 = 0.029 | 0.333/11.334 = 0.029 | 1.000/33.000 = 0.030 | 0.333/11.334 = 0.029 | 0.200/6.800 = 0.029 |
| S9 | 1.000/11.334 = 0.088 | 3.000/33.000 = 0.091 | 0.600/6.800 = 0.088 | 0.600/6.800 = 0.088 | 0.600/6.800 = 0.088 | 1.000/11.334 = 0.088 | 1.000/11.334 = 0.088 | 3.000/33.000 = 0.091 | 1.000/11.334 = 0.088 | 0.600/6.800 = 0.088 |
| S10 | 1.667/11.334 = 0.147 | 5.000/33.000 = 0.152 | 1.000/6.800 = 0.147 | 1.000/6.800 = 0.147 | 1.000/6.800 = 0.147 | 1.667/11.334 = 0.147 | 1.667/11.334 = 0.147 | 5.000/33.000 = 0.152 | 1.667/11.334 = 0.147 | 1.000/6.800 = 0.147 |

**Step 5: Calculate the Weights for Sub-Criteria (C1)**
The weight for each sub-criteria is the average of the normalized values across the rows.

Table 14: the Weights for Sub-Criteria (C1).

| Sub-Criteria | Average (Weight) |
|---|---|
| S1 | 0.088+0.091+0.088+0.088+0.088+0.088+0.088+0.091+0.088+0.088/10=0.0886 |
| S2 | 0.029+0.030+0.029+0.029+0.029+0.029+0.029+0.030+0.029+0.029/10=0.0292 |
| S3 | 0.147+0.152+0.147+0.147+0.147+0.147+0.147+0.152+0.147+0.147/10=0.148 |
| S4 | Same as S3 = 0.148 |
| S5 | Same as S3 = 0.148 |
| S6 | Same as S1 = 0.0886 |
| S7 | Same as S1 = 0.0886 |
| S8 | Same as S2 = 0.0292 |
| S9 | Same as S1 = 0.0886 |
| S10 | Same as S3 = 0.148 |

**Step 6: Normalizing the Pairwise Comparison Matrix for Sub-Criteria (C2)**

Table 15: Normalized the Pairwise Comparison Matrix for Sub-Criteria (C2).

| | S11 (12.333) | S12 (5.533) | S13 (5.533) | S14 (21.000) | S15 (2.009) |
|---|---|---|---|---|---|
| S11 | 1.000/12.333 = 0.081 | 0.333/5.533 = 0.060 | 0.333/5.533 = 0.060 | 3.000/21.000 = 0.143 | 0.200/2.009 = 0.100 |
| S12 | 3.000/12.333 = 0.243 | 1.000/5.533 = 0.181 | 1.000/5.533 = 0.181 | 5.000/21.000 = 0.238 | 0.333/2.009 = 0.166 |
| S13 | 3.000/12.333 = 0.243 | 1.000/5.533 = 0.181 | 1.000/5.533 = 0.181 | 5.000/21.000 = 0.238 | 0.333/2.009 = 0.166 |
| S14 | 0.333/12.333 = 0.027 | 0.200/5.533 = 0.036 | 0.200/5.533 = 0.036 | 1.000/21.000 = 0.048 | 0.143/2.009 = 0.071 |
| S15 | 5.000/12.333 = 0.405 | 3.000/5.533 = 0.543 | 3.000/5.533 = 0.543 | 7.000/21.000 = 0.333 | 1.000/2.009 = 0.498 |

**Step 7: Make Summary of Sub-Criteria Weights (C2)**

Table 16: Summary of Sub-Criteria Weights (C2)

| Sub-Criteria | Weight |
|---|---|
| S11 | 0.089 |
| S12 | 0.202 |
| S13 | 0.202 |
| S14 | 0.044 |
| S15 | 0.464 |

**Step 8: Sub-Criteria Pairwise Comparison Matrix for C3**
Normalize each element by dividing it by the sum of its column.

Table 17: Normalized the Pairwise Comparison Matrix for Sub-Criteria (C3).

| | S16 (5.333) | S17 (5.333) | S18 (12.000) | S19 (1.866) |
|---|---|---|---|---|
| S16 | 1.000/5.333 = 0.188 | 1.000/5.333 = 0.188 | 3.000/12.000 = 0.250 | 0.333/1.866 = 0.178 |
| S17 | 1.000/5.333 = 0.188 | 1.000/5.333 = 0.188 | 3.000/12.000 = 0.250 | 0.333/1.866 = 0.178 |
| S18 | 0.333/5.333 = 0.062 | 0.333/5.333 = 0.062 | 1.000/12.000 = 0.083 | 0.200/1.866 = 0.107 |
| S19 | 3.000/5.333 = 0.562 | 3.000/5.333 = 0.562 | 5.000/12.000 = 0.417 | 1.000/1.866 = 0.536 |

Table 18: Average weight of sub-criteria (C3).

| Sub-Criteria | Average (Weight) |
|---|---|
| S16 | {0.188 + 0.188 + 0.250 + 0.178}/{4} = 0.201 |
| S17 | Same as S16 = 0.201 |
| S18 | {0.062 + 0.062 + 0.083 + 0.107}/{4} = 0.0794 |
| S19 | {0.562 + 0.562 + 0.417 + 0.536}/{4} = 0.5191 |

**Step 9: Calculate the Weights for Sub-Criteria (C3)**
The weight for each sub-criteria is the average of the normalized values across the rows.

Table 19: The weight for each sub-criteria of strength element of SWOT.

| Main Criteria | Sub-Criteria | Sub-Criteria Weight | Main Criteria Weight | Final Weight |
|---|---|---|---|---|
| C1: Government Control | S1 (3) | 0.0886 | 3/15 = 0.200 | 0.0886 × 0.200 = 0.0177 |
| | S2 (1) | 0.0292 | | 0.0292 × 0.200 = 0.0058 |
| | S3 (5) | 0.148 | | 0.148 × 0.200 = 0.0296 |
| | S4 (5) | 0.148 | | 0.148 × 0.200 = 0.0296 |
| | S5 (5) | 0.148 | | 0.148 × 0.200 = 0.0296 |
| | S6 (3) | 0.0886 | | 0.0886 × 0.200 = 0.0177 |
| | S7 (3) | 0.0886 | | 0.0886 × 0.200 = 0.0177 |
| | S8 (1) | 0.0292 | | 0.0292 × 0.200 = 0.0058 |
| | S9 (3) | 0.0886 | | 0.0886 × 0.200 = 0.0177 |
| | S10 (5) | 0.148 | | 0.148 × 0.200 = 0.0296 |
| C2: Human Resources & Water | S11 (1) | 0.089 | 5/15 = 0.333 | 0.089 × 0.333 = 0.0296 |
| | S12 (3) | 0.202 | | 0.202 × 0.333 = 0.0673 |
| | S13 (3) | 0.202 | | 0.202 × 0.333 = 0.0673 |
| | S14 (1) | 0.044 | | 0.044 × 0.333 = 0.0147 |
| | S15 (5) | 0.464 | | 0.464 × 0.333 = 0.1547 |
| C3: Cost of Construction | S16 (3) | 0.201 | 7/15 = 0.467 | 0.201 × 0.467 = 0.0939 |
| | S17 (3) | 0.201 | | 0.201 × 0.467 = 0.0939 |
| | S18 (1) | 0.079 | | 0.079 × 0.467 = 0.0369 |
| | S19 (5) | 0.519 | | 0.519 × 0.467 = 0.2424 |

The results of the questionnaire for SWOT strength elements produced three alternatives with a high importance factor that was agreed upon by the experts, as shown in the Table 20. It is noted that the greatest weight given by experts is to the use of modern technology in management and maintenance work due to saving time and money and preserving the facility from misuse. This is consistent concerns obtained by[52] regarding the maintenance of the Abu Ghraib Project, which

recommended adopting modern maintenance methods. This would raise the efficiency of performance and the quality of the water used. not neglecting periodic maintenance, and training scientifically technical staff capable of reducing operating costs. The use of modern technology is not limited to irrigation works only. [75] applied numerical modelling (MIKE 11, MIKE 21, MIKE FLOOD) combined with GIS technology to simulate flooding due to the collapse of Dong Be reservoir, Thanh Hoa, Vietnam.

Table 20: Highest priority of Strength element.

| Criteria | Description | Final Weight | Comments |
|---|---|---|---|
| S19 | modern technology and machinery need to be used in irrigation canal maintenance & operation. | 0.2424 | 77.5 % A percentage of the sample agreed the necessity of using modern technology into maintenance work. |
| S15 | A real and sufficient database on losing in conveyance networks | 0.1547 | 80% of experts confirmed that there is no real database on the amount of quantity lost |

B. Weakness Element
Government control and management (C1) = 5
Human resources and use of water resources (C2) =7
Cost of construction & maintenance (C3) = 3

Table 21: Pairwise comparison matrixes for the criteria of Weakness element.

| Weakness | C1 | C2 | C3 | Average Value |
|---|---|---|---|---|
| C1 | 0.379 | 0.583 | 0.824 | 0.595 |
| C2 | 0.263 | 0.333 | 0.476 | 0.357 |
| C3 | 0.158 | 0.083 | 0.190 | 0.144 |

| C1 | W1 | W2 | W3 | W4 | W5 | W6 | W7 | W8 | Average Value | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **W1** | 0.065 | 0.020 | 0.020 | 0.02 | 0.004 | 0.001 | 0.02 | 0.004 | 0.023 | | |
| **W2** | 0.196 | 0.333 | 0.333 | 0.333 | 0.050 | 0.008 | 0.333 | 0.050 | 0.211 | | |
| **W3** | 0.196 | 0.333 | 0.333 | 0.333 | 0.050 | 0.008 | 0.333 | 0.050 | 0.211 | | |
| **W4** | 0.196 | 0.333 | 0.333 | 0.333 | 0.050 | 0.008 | 0.333 | 0.050 | 0.211 | | |
| **W5** | 0.365 | 0.277 | 0.277 | 0.277 | 0.500 | 0.111 | 0.277 | 0.500 | 0.324 | | |
| **W6** | 0.475 | 0.407 | 0.407 | 0.407 | 0.333 | 0.500 | 0.407 | 0.333 | 0.423 | | |
| **W7** | 0.196 | 0.333 | 0.333 | 0.333 | 0.050 | 0.008 | 0.333 | 0.050 | 0.211 | | |
| **W8** | 0.365 | 0.277 | 0.277 | 0.277 | 0.500 | 0.111 | 0.277 | 0.500 | 0.324 | | |
| | | | | | | | | | | | |
| **W9** | 0.067 | 0.020 | 0.067 | 0.02 | 0.067 | 0.02 | 0.048 | **C3** | **W15** | **W16** | **W17** |
| **W10** | 0.200 | 0.333 | 0.200 | 0.333 | 0.200 | 0.333 | 0.289 | **W15** | 0.063 | 0.008 | 0.003 |
| **W11** | 0.067 | 0.020 | 0.067 | 0.020 | 0.067 | 0.020 | 0.048 | **W16** | 0.313 | 0.625 | 0.167 |
| **W12** | 0.200 | 0.333 | 0.200 | 0.333 | 0.200 | 0.333 | 0.289 | **W17** | 0.625 | 0.375 | 0.833 |
| **W13** | 0.067 | 0.020 | 0.067 | 0.020 | 0.067 | 0.020 | 0.048 | **Average Value** | 0.025 | 0.368 | 0.0.611 |
| **W14** | 0.200 | 0.333 | 0.200 | 0.333 | 0.200 | 0.333 | 0.289 | | | | |
| | **Sub Criteria** | **W1** | **W2** | **W3** | **W4** | **W5** | **W6** | **W7** | **W8** | **W9** | **W10** |
| | **Final Weight** | 0.0137 | 0.1254 | 0.1254 | 0.1254 | 0.1928 | 0.2914 | 0.1254 | 0.1928 | 0.0171 | 0.1031 |
| | **Sub Criteria** | **W11** | **W12** | **W13** | **W14** | **W15** | **W16** | **W17** | | | |
| | **Final Weight** | 0.0171 | 0.1031 | 0.0171 | 0.1031 | 0.0036 | 0.0531 | 0.0879 | | | |

The weightiest and influential alternatives were assigned to the SWOT elements and are summarized in the Table 22 as bellow.

Table 22: Highest priority of Weakness element.

| Criteria | Description | Final Weight | Comments |
|---|---|---|---|
| W6 | There is a delay in converting all unlined conveyance canals to lined or closed conduits | 0.2914 | 75 % of the experts agreed with this assumption |
| W8 | The lack of financial allocations allocated by the government for water conveyance projects. | 0.1928 | 63% of the opinions confirm that there is Insufficient financial allocations in the annual budget for construction and maintenance. |
| W5 | There is a negligence on the part of the government in preserving Iraq's water rights from neighboring countries. | 0.1928 | More than half of the elected opinions confirmed that the government did not neglect to conclude agreements with neighbouring countries |

Upon reviewing the results of the questionnaire, it became clear that more attention was paid to allocating additional funds to remove unlined canals and convert them to lined ones or to use pipes as a means of conveyance, should not forget the emphasis on concluding clear international agreements that preserve Iraq’s right to its water shares. These results are confirmed by many researches, as [53], [54] and [55]. Conveyance losses in the presence of unlined clay canals may reach more than 40%, as mentioned in [48], who reported conveyance losses in Assiut, Egypt.

C. Opportunity Element
   Government control and management (C1) = 9
   Human resources and use of water resources (C2) = 7
   Cost of construction & maintenance (C3) = 5

Table 22: Pairwise comparison matrixes for main & sub criteria of Opportunity element.

| Opportunity | C1 | C2 | C3 | Average Value |
|---|---|---|---|---|
| C1 | 0.2632 | 0.2500 | 0.2381 | 0.2504 |
| C2 | 0.3684 | 0.3500 | 0.3333 | 0.3506 |
| C3 | 0.1579 | 0.1000 | 0.1429 | 0.1336 |

| C1 | O1 | O2 | O3 | O4 | O5 | O6 | O7 | Average Value |
|---|---|---|---|---|---|---|---|---|
| **O1** | 0.061 | 0.120 | 0.120 | 0.061 | 0.04 | 0.020 | 0.120 | 0.0774 |
| **O2** | 0.020 | 0.040 | 0.040 | 0.020 | 0.026 | 0.020 | 0.040 | 0.0296 |
| **O3** | 0.020 | 0.040 | 0.040 | 0.020 | 0.026 | 0.020 | 0.040 | 0.0296 |
| **O4** | 0.061 | 0.120 | 0.120 | 0.061 | 0.040 | 0.020 | 0.120 | 0.0774 |
| **O5** | 0.183 | 0.200 | 0.200 | 0.183 | 0.120 | 0.066 | 0.200 | 0.1647 |
| **O6** | 0.427 | 0.280 | 0.280 | 0.427 | 0.360 | 0.333 | 0.280 | 0.3411 |
| **O7** | 0.020 | 0.040 | 0.040 | 0.020 | 0.026 | 0.020 | 0.040 | 0.0296 |

| C2 | O8 | O9 | O10 | O11 | O12 | Average Value | C3 | O13 | O14 | O15 | Average Value |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **O8** | 0.0676 | 0.0625 | 0.0676 | 0.0625 | 0.0270 | 0.0575 | **O13** | 0.4865 | 0.5385 | 0.875 | 0.6333 |
| **O9** | 0.2027 | 0.1875 | 0.2027 | 0.1875 | 0.0811 | 0.1723 | **O14** | 0.4865 | 0.3846 | 0.625 | 0.4987 |
| **O10** | 0.0676 | 0.0625 | 0.0676 | 0.0625 | 0.0270 | 0.0575 | **O15** | 0.0270 | 0.0769 | 0.500 | 0.1680 |
| **O11** | 0.2027 | 0.1875 | 0.2027 | 0.1875 | 0.0811 | 0.1723 | | | | | |
| **O12** | 0.4595 | 0.5000 | 0.4595 | 0.5000 | 0.7838 | 0.5406 | | | | | |
| **Sub Criteria** | **O1** | **O2** | **O3** | **O4** | **O5** | **O6** | **O7** | **O8** | **O9** | **O10** | |
| **Final Weight** | 0.0194 | 0.0074 | 0.0074 | 0.0194 | 0.0412 | 0.0855 | 0.0074 | 0.0201 | 0.0604 | 0.0201 | |
| **Sub Criteria** | **O11** | **O12** | **O13** | **O14** | **O15** | | | | | | |
| **Final Weight** | 0.0604 | 0.1896 | 0.0846 | 0.0666 | 0.0224 | | | | | | |

O12: Which symbolizes the opportunities for concluding clear future agreements with neighboring countries to regulate water imports from the Tigris and Euphrates rivers.

Table 23: Pairwise comparison matrix for main & sub criteria of Threats element

| Threats | C1 | C2 | C3 | Average Value |
|---|---|---|---|---|
| **C1** | 0.5294 | 0.5294 | 0.5294 | 0.5294 |
| **C2** | 0.4118 | 0.4118 | 0.4118 | 0.4118 |
| **C3** | 0.2941 | 0.2941 | 0.2941 | 0.2941 |

| C1 | T1 | T2 | T3 | T4 | T5 | T6 | T7 | Average Value |
|---|---|---|---|---|---|---|---|---|
| **T1** | 0.1176 | 0.1846 | 0.1176 | 0.1846 | 0.2059 | 0.2059 | 0.2059 | 0.1746 |
| **T2** | 0.0918 | 0.1231 | 0.0918 | 0.1231 | 0.1607 | 0.1607 | 0.1607 | 0.1303 |
| **T3** | 0.1176 | 0.1846 | 0.1176 | 0.1846 | 0.2059 | 0.2059 | 0.2059 | 0.1746 |
| **T4** | 0.0918 | 0.1231 | 0.0918 | 0.1231 | 0.1607 | 0.1607 | 0.1607 | 0.1303 |
| **T5** | 0.0654 | 0.0923 | 0.0654 | 0.0923 | 0.1176 | 0.1176 | 0.1176 | 0.0954 |
| **T6** | 0.0654 | 0.0923 | 0.0654 | 0.0923 | 0.1176 | 0.1176 | 0.1176 | 0.0954 |
| **T7** | 0.0654 | 0.0923 | 0.0654 | 0.0923 | 0.1176 | 0.1176 | 0.1176 | 0.0954 |

| C2 | T8 | T9 | T10 | Average Value | C3 | T11 | T12 | Average Value |
|---|---|---|---|---|---|---|---|---|
| **T8** | 0.0833 | 0.1231 | 0.1111 | 0.1058 | **T11** | 0.5 | 0.5 | 0.5 |
| **T9** | 0.5833 | 0.3077 | 0.2593 | 0.3834 | **T12** | 0.5 | 0.5 | 0.5 |
| **T10** | 0.3333 | 0.5692 | 0.6296 | 0.5107 | | | | |

| Sub Criteria | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | T9 | T10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Final Weight** | 0.0924 | 0.0690 | 0.0924 | 0.0690 | 0.0505 | 0.0505 | 0.0505 | 0.0435 | 0.1578 | 0.2104 |
| **Sub Criteria** | **T11** | **T12** | | | | | | | | |
| **Final** | 0.1470 | 0.1470 | | | | | | | | |

Table 24: Highest priority of Threats element.

| Criteria | Description | Final Weight | Comments |
|---|---|---|---|
| T10 | There is a chance that oversight of irrigation canals in remote areas will be neglected, leading to an increase in violations. | 0.2104 | 100% of experts accepted with this assumption |
| T9 | The agreements and laws are restrict and define the support and implementation of irrigation project plans. | 0.1578 | 62.5 % of experts agrees with that solution |

It is clear from the above results the importance of state control over remote areas for the purpose of establishing irrigation projects and increasing agricultural production. Report of (MoWR) in its annual report for the years 2013 to 2017 showed the evidence regarding to increase in losses of conveyance networks due to the presence of violations in water distribution networks that cannot be controlled due to the weakness of the necessary power and its distance from city centers. Currently, the values that have the most influence on the relative weight for the main and sub criteria of four SWOT elements can be sort as shown in table 25.

Table 25: Highest relative weight of sub criteria

| Criteria | Description | Final Weight | Comments |
|---|---|---|---|
| Strengths | Cost of construction & maintenance | S19 | 0.2424 |
| Weaknesses | Government control and management | W6 | 0.2915 |
| Opportunities | Human resources and use of water resources | O12 | 0.1896 |
| Threats | Human resources and use of water resources | T10 | 0.2104 |

According to Figure 13, after knowing the weights of each sub criterion of the questionnaire and choosing the most influential, it is necessary to account the effect of the basic SWOT element to specify the most important element among the four elements (Table 25). It becomes clear that the criterion of weakness in the system represented by the delay in converting all unlined conveyance canals to lined or closed conduits. It is the most influential factor, according to experts, because it causes a lot of water losses despite the water scarcity and the failure to achieve the desired goal of its construction due to the increase in the rate of evaporation and seepage losses.

- Strength (S) importance = 5, with S19 having a final weight of 0.2424
- Weakness (W) importance = 7, with W6 having a final weight of 0.2915
- Opportunities (O) importance = 3, with O12 having a final weight of 0.1896
- Threats (T) importance = 7, with T10 having a final weight of 0.2104
- Step-by-step calculation:
    - Strength (S):
    - Overall weight for S19=Importance of Strength×Final weight of S19=5×0.2424=1.212
- Weakness (W):
    - Overall weight for W6=Importance of Weakness×Final weight of W6=7×0.2915=2.0405
- Opportunities (O):
    - Overall weight for O12=Importance of Opportunities×Final weight of O12=3×0.1896=0.56 88

- Threats (T):
    - Overall weight for T10=Importance of Threats×Final weight of T10=7×0.2104=1.4728

Table 26: adjusted weights for most significant factor according to SWOT weight.

| SWOT Element | Sub-Criterion | Final Weight | Importance Weight | Adjusted Weight |
|---|---|---|---|---|
| Strengths | S19 | 0.2424 | 5 | 1.212 |
| Weakness | W6 | 0.291 | 7 | 2.0405 |
| Opportunity | O12 | 0.189 | 3 | 0.548 |
| Threats | T10 | 0.2104 | 7 | 1.4728 |

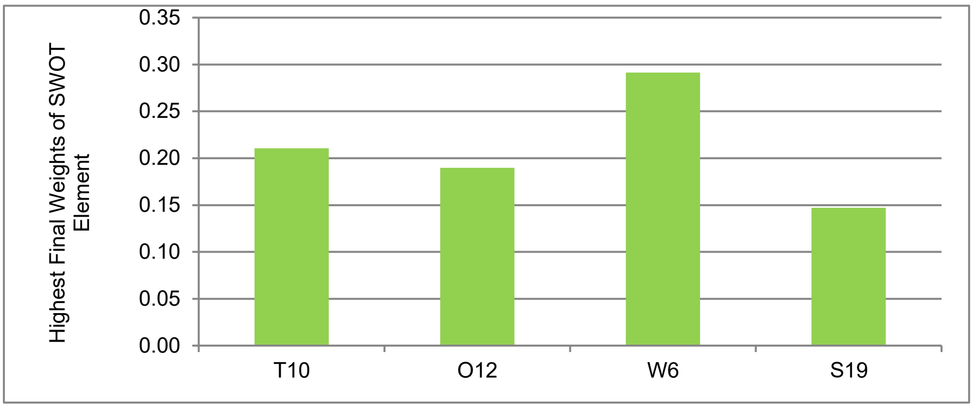

Fig.13: Prioritization of most important activities.

The obtained results (Figure 13) represents the prioritization of most important activities of sub-criteria within a SWOT elements analysis framework using the AHP method, focused on water resource management improvement.

The weakness element (W6) indicate delay and huge problem of losing water due to delay in linning canals or convert to pipes lines as also recommended by [56] and [57], their recommendations concerned the Hilla irrigation project in Iraq and use of local materials for canal lining Rawakeeb Research Station (RRS) in Egypt Next activities with high weighting is T10 threats elements with issues of remote areas in conveyance systems and modern technology should be taking part, it agrees with what was stated in [58] about application of remote sensing and GIS to study water quality changes and spectral analysis of Tigris River within Mosul City, north of Iraq.

[59] matches same recommendations with (O12) opportunity element explores the political dynamics and opportunities for trans boundary water cooperation in the Euphrates-Tigris river system. Finally, the integration of AHP with SWOT analysis provides a structured decision-making approach that balances both quantitative and qualitative aspects of strategic planning, offering robust insights for water resources management [60]. This method has been successfully applied in various fields, including environmental management and engineering, underscoring its versatility and effectiveness in addressing complex decision-making scenarios like in [61].

### 3.4 Results of Questionnaires Rounds

Sensitivity analysis means exploring how changes in the importance of SWOT elements and slight modifications to sub-criteria weights affect the final decision. Here's how we'll proceed step by step:

1) Base Scenario (Reference)

The base scenario with the original importance of SWOT elements and sub-criteria final weights as shown in Figure 13 and Table 26 before is illustrated that most significant factor: W6, with the highest overall significance.

**Scenario 1**: Changing Importance of SWOT Elements

- Objective: Increase the importance of Strength to 7 and decrease the importance of Weakness to 5.

The new weights will be as follows:

- Strength importance = 7
- Weakness importance = 5

Let's recalculate the overall significance:

1. Strength (S19): Overall weight for S19=7×0.2424=1.6968
2. Weakness (W6): Overall weight for W6=5×0.2915=1.4575
3. Opportunities (O12) (remains the same): Overall weight for O12=3×0.1896=0.5688
4. Threats (T10) (remains the same): Overall weight for T10=7×0.2104=1.4728

**Results of Scenario 1:**

Table 27: Results of Scenario 1 of sensitivity analysis.

| SWOT Element | Sub-Criteria | Final Weight of Sub-Criteria | Importance of SWOT Element | Overall Significance |
|---|---|---|---|---|
| Strength | S19 | 0.2424 | 7 | 1.6968 |
| Weakness | W6 | 0.2915 | 5 | 1.4575 |
| Opportunities | O12 | 0.1896 | 3 | 0.5688 |
| Threats | T10 | 0.2104 | 7 | 1.4728 |

- In this scenario, S19 (Strength) becomes the most significant factor (1.6968), surpassing W6 (Weakness).
- W6 decreases in significance due to the reduced importance of the Weakness element.
- Threats (T10) maintains its importance, with a significance value slightly higher than Weakness.
- (S19) activity means The use of modern technology in maintenance work is one of the most important factors that reduce high maintenance costs and increase the life of hydraulic facilities. modern technology and machinery need to be used in irrigation canal operation & maintenance. It is consistent with what was stated by [67] who presented a study carry out in western Iraq contains using a Support Vector Machine SVM-based technique for accurately predicting irrigation project durations, addressing delays caused by unthoughtful employer estimations, and significantly improving forecast accuracy compared to linear regression models. [68] surveyed water resource management in Iraq's Western Desert, using remote sensing, field data, and modeling to assess surface/groundwater and analyze pond characteristics via digital elevation models. Modern technological programs can be used to determine the hydrological advantages of places as in [76] conducted to determine the hydrological and morphometric characteristics of the Wad Ramli region, Sudan. The Digital Elevation Model (DEM) was obtained and then processed within the ArcGIS 10.8 program.

**Scenario 2**: Swapping Importance of Opportunities and Threats

- Objective: Increase the importance of Opportunities to 7 and decrease the importance of Threats to 3.

New importance weights:

- Opportunities importance = 7
- Threats importance = 3

Recalculating the overall significance:

1. Strength (S19) (remains the same): Overall weight for S19=5×0.2424=1.212
2. Weakness (W6) (remains the same): Overall weight for W6=7×0.2915=2.0405
3. Opportunities (O12): Overall weight for O12=7×0.1896=1.3272
4. Threats (T10): Overall weight for T10=3×0.2104=0.6312

**Results of Scenario 2:**

Table 28: Results of Scenario 1 of sensitivity analysis.

| SWOT Element | Sub-Criteria | Final Weight of Sub-Criteria | Importance of SWOT Element | Overall Significance |
|---|---|---|---|---|
| Strength | S19 | 0.2424 | 5 | 1.212 |
| Weakness | W6 | 0.2915 | 7 | 2.0405 |
| Opportunities | O12 | 0.1896 | 7 | 1.3272 |
| Threats | T10 | 0.2104 | 3 | 0.6312 |

- Weakness (W6) remains the most significant factor in this scenario.
- Opportunities (O12) becomes much more significant with a value of 1.3272, overtaking Strength (S19).
- Threats (T10) drops in significance, reflecting the reduced importance of Threats in this scenario. This is very similar to the results of the original scenario.

**Scenario 3**: Adjusting Sub-Criteria Weights by ±10%

- Objective: Apply a 10% increase and decrease to the final weight of the most significant sub-criteria and recalculate.

Let's adjust the weights for W6 (Weakness), T10 (Threats), and S19 (Strength) by ±10%:

1. Strength (S19):
   - Original final weight = 0.2424

- +10% adjustment: 0.2424 × 1.10 = 0.2666
- -10% adjustment: 0.2424 × 0.90 = 0.2182

2. Weakness (W6):
   - Original final weight = 0.2915
   - +10% adjustment: 0.2915 × 1.10 = 0.3207
   - -10% adjustment: 0.2915 × 0.90 = 0.2624
3. Threats (T10):
   - Original final weight = 0.2104
   - +10% adjustment: 0.2104 × 1.10 = 0.2314
   - -10% adjustment: 0.2104 × 0.90 = 0.1894

After adjusting, recalculate the overall significance for each SWOT element.

**Summary of Sensitivity Analysis:**

1. Changing the Importance of SWOT Elements:
   - S19 (Strength) can become the most significant factor if Strength is given more importance.
   - Weakness (W6) consistently remains significant in most scenarios.
2. Adjusting Sub-Criteria Weights:
   - Small changes (±10%) in the final weights of sub-criteria shift the overall significance but do not drastically alter the ranking of most significant factors.

The study of the Hornád River [69] Basin applied a combined SWOT and AHP and analyzing with sensitivity approach to propose a sustainable management model for the river basin. The research focused on analyzing and prioritizing various indicators of water quality and management strategies. The study outlined the strengths, weaknesses, opportunities, and threats (SWOT) specific to the basin and applied the Analytic Hierarchy Process (AHP) to determine the relative importance of each factor for sustainable development.

### 3.5 Potential biases in expert opinions and their impact on the findings

In addressing potential biases in expert opinions during SWOT-AHP analysis for water resources management, several measures were implemented. AHP mitigates bias through pairwise comparisons and consistency checks, ensuring reliable judgments. The SWOT-AHP integration allows for a structured, quantitative assessment of SWOT factors, reducing subjectivity [70]. The diversity of the 80-expert panel, representing various academic qualifications and specializations, further balances potential biases [71]. Anonymity through the Delphi method ensures freedom of expression, minimizing peer influence [72]. Similar studies, such as [73] and [74], demonstrate that AHP, when paired with expert input, mitigates individual biases in decision-making for hydrological projects. Ultimately.

This methodology provides a balanced and systematic approach to decision-making in water resources engineering, enhancing the robustness of the findings.

## 4 Conclusion

The primary aim of this study was to analyze the strengths, weaknesses, opportunities, and threats (SWOT) of water resource management in Iraq using the Analytical Hierarchy Process (AHP) method. By integrating both quantitative and qualitative aspects, the research provided a comprehensive framework for strategic planning in this critical sector.

The study's key findings are as follows:

1) Weaknesses: The most significant weakness identified is the delay in converting unlined canals to lined or closed canals, leading to substantial water conveyance losses. This inefficiency is costing the state significant sums of money due to seepage and filtration through mud-lined canals. Additionally, there is a lack of specialized technical staff for periodic maintenance, exacerbating the problem by delaying necessary repairs and leading to structural damage.

2) Threats: The research highlights the absence of a clear maintenance plan and appropriate budgeting, along with negligence from the staff towards maintenance requests. This lack of attention

to maintenance poses a significant threat to the water management system's efficiency and sustainability.

3) Opportunities: One of the key opportunities identified is the recent agreements signed to preserve Iraq's water shares. These agreements can potentially improve water management if effectively implemented.

4) Strengths: The strengths of the current water management system were also evaluated, although specific strengths were less emphasized compared to weaknesses and threats.

Based on these findings, the study concludes with several crucial points and recommendations:

- Infrastructure Improvement: There is an urgent need to accelerate the transformation of unlined canals to lined or closed systems to reduce water losses and improve efficiency.
- Technical Expertise: Increasing the number of specialized technical staff and providing regular training is essential to ensure timely and effective maintenance.
- Modern Technology: Adopting modern technologies such as satellite monitoring and the use of international Internet-based monitoring stations can significantly enhance the management and preservation of water resources.
- Maintenance Planning: Developing a clear maintenance plan with appropriate budgeting is critical to address the current threats and prevent future inefficiencies.
- International Cooperation: Strengthening and implementing agreements with neighboring countries is vital to secure Iraq's water rights and ensure sustainable water resource management.

These recommendations aim to provide actionable steps for policymakers and stakeholders to improve water resource management in Iraq, ensuring long-term sustainability and efficiency.

### 4.1 Limitations of the Study

One of the primary limitations of this research is the reliance on expert judgment in the SWOT-AHP analysis. While the study involved a diverse group of 80 experts from various disciplines, biases in subjective evaluations can still arise, potentially affecting the rankings of the SWOT factors. Another limitation pertains to the focus on Iraq’s water management system, which may limit the generalizability of the findings to other regions with different environmental, political, and infrastructural conditions. Furthermore, the study predominantly emphasizes infrastructural and administrative aspects, while not deeply exploring social or environmental impacts that may arise from the proposed changes.

### 4.2 Future Research Directions

Future studies could address these limitations by expanding the research scope to include more comprehensive socio-environmental factors and exploring the long-term impacts of the proposed recommendations. Comparative studies between Iraq and other countries facing similar water management challenges could also provide valuable insights. Additionally, future research should consider incorporating real-time data analytics and more advanced decision-making models, such as integrating AHP with machine learning techniques, to further refine the prioritization of strategies for water resource management. Finally, the implementation and monitoring of the suggested strategies, particularly the agreements on water shares, should be an area for continued research to evaluate their effectiveness over time.

This expanded perspective could provide policymakers with more actionable insights and help guide future interventions in the field of water resource management.

## 5. Declarations

Conceptualization, Zyad and Mahmoud; methodology, Zyad and Mahmoud; validation, Zyad and Mahmoud; formal analysis, Zyad and Mahmoud; investigation, Zyad; resources Zyad and Mahmoud; data curation, Zyad and Mahmoud.; writing—original draft preparation, Zyad.; writing—review and editing, Zyad.; visualization, Zyad; supervision, Mahmoud; project administration, Zyad ; funding acquisition, Zyad and Mahmoud ,All authors have read and agreed to the published version of the manuscript.

### 5.2 Data Availability Statement

Data available in a publicly accessible repository: The data presented in this study are openly available.

### 5.3 Funding

Corresponding Authors are responsible for identifying and declaring all funding sources received for the research submitted to the journal. During submission, Corresponding Authors will also be asked to provide the Funder, Award Number and Grant Recipient. If there are no funders to be identified the corresponding author must state "Funding information is not available." Funding information will be entered during the submission stage and will be included in the final publication

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### 5.5 Conflicts of Interest

The authors declare no conflict of interest.

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