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Multi-Criteria Analysis for Evaluating Constructed Wetland as a Sustainable Sanitation Technology, Jordan Case Study

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Abstract: There is a growing demand for integrating an assessment tool to select wastewater treatment alternatives based on sustainability in the Jordanian wastewater sector. The sector in Jordan has a unique and critical situation that has raised concerns among stakeholders, including donors, and international and national organizations, to carefully select a sustainable treatment system for each case. The Jordanian government set a tool to distinguish between treatment systems, and this tool is mainly focused on financial criteria. However, the sector needs to integrate assessment tools with a wider consideration of other sustainability criteria. Usually, stakeholders are not equipped with a clear methodology to perform sustainability assessments. Therefore, this study proposes and develops a Multi-Criteria Analysis (MCA) tool to evaluate wastewater treatment alternatives from a sustainability perspective for a case study in Jordan—Al Azraq town. Firstly, the study explored the decision and organizational context of the wastewater sector through several interviews. Secondly, assessment criteria and indicators were proposed to compare three proposed treatment alternatives. Finally, the Analytical Hierarchy Process (AHP) was applied with composite scores to evaluate wastewater treatment alternatives. Finally, The results of the composite scores indicated that French Constructed Wetland (FCW) was the best option for this case study, with a score of 3.13, followed by Stabilization Pond (SP) as the second sustainable option, with a score of 2.67, and lastly, Activated Sludge (AS), with a score of 2.07. Several conclusions have been highlighted during the process development, such as the importance of selecting sustainability indicators carefully, and engaging stakeholders during the design and implementation of the assessment.

Keywords: nature-based solution; constructed wetlands; wastewater treatment plants; multi-criteria analysis; analytical hierarchy process; decision-making support

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1. Introduction

In Jordan, the daily water share per capita is approximately 100 L, and this fact has ranked Jordan as the second poorest country for water availability per person [1]. The country has been suffering from water scarcity that is caused by rapid population growth, a huge influx of refugees, and hydro-political tensions in the Middle East [2]. This has led to a continuously increasing demand on water that is exceeding the potential of the country's water resources [3]. The well-known climate change impacts have worsened the Jordanian water sector by adding more challenges to the availability and variability of precipitation, extreme events, and heats waves, and these facts have created an imbalance in water management and have enlarged the gap between the demand and the water supply [4].

According to the Ministry of Water and Irrigation's (MWI's) reports, the main sources of water in Jordan are (i) groundwater (59%), (ii) surface water (27%), (iii) treated wastewater (14%), and additional resources (desalination) [1,5]. The three main sectors that are competing for water resources are domestic, agriculture, and industry [1,5].

Although the Jordanian government is considering treated wastewater as a part of the annual water budget used in the agriculture sector, the sanitation sector still requires modifications and more sustainable solutions. To overcome this challenge and to enhance the reuse of wastewater, the Jordanian government has prepared the National Water Strategy 2016–2025. The strategy focuses on building a resilient sector based on a unified approach for a comprehensive social, economic, and environmentally viable water sector development. The national policy includes a (Decentralization Wastewater Management Policy), which aims to activate the decentralization concept in managing wastewater for small and scattered communities in order to serve them with sanitation services and to enhance the collection and the reuse of wastewater [5,6]. The MWI has established an inter-ministerial National Implementation Committee for Effective Integrated Wastewater Management (NICE) in order to develop regulatory and administrative tools for implementing and certifying decentralized wastewater management (DWWM) systems in Jordan [5–7]. At the centralization level, MWI has prepared a plan to upgrade, modify, and expand the existent wastewater treatment plants in order to increase the amount of treated wastewater [5]. However, 35% of Jordanians are still not connected to sewer networks and wastewater treatment plants, and they have onsite solutions such as septic tanks (mostly unsealed) which is not only causing environmental and health risks, but is also affecting the future potential for reusing treated wastewater [1,3,8].

Al Azraq town is one of the unserved towns with sanitation system. It is located in the eastern part of Jordan and it has a population of more than 15,000 people, who are not served with a treatment system or a sewer network. Residents in this town have onsite solutions at the household level, and their wastewater is assembled in a collection tank via gravity [8]. The collection tanks have no standard sizes, and they can be classified into (i) fully sealed septic tank, (ii) fully sealed septic tank with infiltration chamber, (iii) cesspits with rigid top-slab and walls, and not sealed, and (iv) cesspit with make-shift top slab and unsealed. According to the Azraq Municipality and based on the site assessments, the most commonly used ones are unsealed tanks, which cause the seepage of wastewater. The sewage is collected via desludging trucks and is disposed without further treatment to an illegal dumpsite, which contributes to pollution in the area and poses a very high risk for human health and for the environment.

On the other hand, Al Azraq town is located over a main groundwater basin called Al Azraq Basin, which is considered as a unique source of fresh water for the desert. The total area of Al Azraq basin is 12,414 km^2 and it extends from the Syrian borders in the north to the Saudi borders in the south, where 94% of the Azraq basin area is located in Jordan and the rest in Syria. Nowadays, around 70 MCM/year of drinking water are being pumped to Amman and Zarqa from the basin, and this covers 10% of the groundwater yearly abstraction in Jordan [1,9,10]. The illegal disposal causes the infiltration of non-treated wastewater in the lowest point of the dumpsite area, which increases the risk of polluting the aquifer [11]. Al Azraq has also a wetland reserve in the heart of the basin, where millions of migratory birds rest in it every year during their travels from Siberia to Africa, and vice versa. This natural wetland needs to be protected from the contamination of water and the environment caused by the inappropriate sanitation system [10]. Even though the municipality knows its obligation to treat the wastewater in a centralized treatment plant, the cost of the sewage trucking is not feasible.

The critical situation of Al Azraq has caught the attention of many non-governmental organizations (NGOs) who are working in sanitation and who are willing to implement projects of wastewater treatment in Jordan. An international donor has allocated a certain budget to serve the town with a sustainable sanitation solution that can achieve the following benefits:

1. Reduction of the health risk related to water contamination,
2. Reduction of the existing environmental risk,
3. Provide a new source of water for the community,
4. Improvement of the resilience to climate change,

5. Development of a model that could be repeated in the future.

Although the funds have been allocated, the selection of the most appropriate and sustainable treatment technology that can be suitable for the Jordanian context in general and for Al Azraq town specifically is required. A sustainability assessment tool was needed to help the decision-makers with the selection of the most appropriate technology for this context.

The MWI has prepared a decision-support tool called the "Assessment of Local Lowest-Cost Wastewater Solutions" (ALLOWS) decision-support tool. The ALLOWS tool is used to identify most cost-efficient wastewater management solutions, and to determine whether a centralized or a decentralized approach is economically more appropriate for a specific case. The ALLOWS tool focuses on financial indicators for different wastewater scenarios, and accordingly enables planners and decision-makers to perform a comparative analysis to identify the best solutions for the wastewater management problem. The ALLOWS tool mainly considers the financial criteria and part of the technical criteria in comparing treatment scenarios without considering the other sustainability criteria such as the institutional, environmental, and the social; as a result, several sanitation projects have previously faced social rejections, and other projects have faced the overlapping of institutional responsibility, which has led to a change in the operation scenarios. Therefore, it is necessary to integrate a sufficient analysis tool that consider a wider vision of sustainability before making the asset decision and to carefully evaluate, assess, and select sustainable wastewater treatment processes or technologies [6,7].

The aim of this research is to present to the Jordanian water and wastewater sector a practical example of using MCA as a sustainability assessment tool, in order to integrate and to consider the tool in the decision-making process. The practical example considers the use of MCA to assess, compare, and evaluate the sustainability of different wastewater treatment options for Al Azraq town as a case study.

This paper covers a general background on the sanitation situation in Jordan and in the selected case study, and a general introduction on sustainability assessment tools, followed by a detailed methodology that has been used, the results and the main observations, and finally, the discussion and conclusions.

2. Sustainability Assessment Tools

Nowadays, decision-making processes are increasingly considering sustainability assessments [12,13]. Sustainability assessments contain several assessment tools and are basically linked with the long-term practice impact. In general, sustainability assessments evaluate the future impacts of current or planned interventions, and inform decision makers [14–16].

Several tools have been developed and studied to perform sustainability assessments. According to the literature, the sustainability assessment can be completed in three approaches. The first approach is the biophysical approach, which considers the flow of resources and environmental impacts for evaluations such as Life Cycle Assessment (LCA); the second approach is the monetary and economical approach, which aims to deliver valuations based on the subjective value preference of stakeholders such as the Cost–Benefit Analysis (CBA); the last approach is indicator-based tools that include the selection of indicators, calculations of weights, and scoring and aggregation, such as Multi-Criteria Analysis (MCA) [14,16,17]. MCA is a group of approaches that utilize multiple criteria and identify the best alternative based on the preference systems of stakeholders or decision makers [18]. MCA provides a rational and a coherent decision-making process through the application of a standardized method. There are several methods in MCA, for example, the Analytical Hierarchy Process (AHP) [16]. MCA has been usually used in the fields of environmental science and management. Comprehensive reviews on the detailed application of MCA were provided by Kiker et al. [19], Cegan et al. [20], Huang et al. [21], and Ling et al. [16].

3. Multi-Criteria Analysis (MCA)

Multi-criteria analysis (MCA) or multi-criteria decision making (MCDM) is a valuable and increasingly widely used tool to help decision making where there is a choice to be made between alternatives. It is particularly useful as a tool for sustainability assessment where a complex and inter-connected range of environmental, social, and economic issues must be considered, where objectives are often competing, and where doing the trade-offs is unavoidable. It provides a robust and transparent decision-making structure, making explicit the key considerations and the values assigned to them, and providing opportunities for not just stakeholders, but also the community's participation. MCA can be applied at all levels of decision-making; from the consideration of project alternatives to the policy decisions, MCA is guiding an evolution towards selecting the most sustainable alternative. MCA has been widely applied in environmental management (water, air, energy, natural resources, and solid waste) or interventions/tools applications (stakeholders, strategies, sustainability, and GIS) [19,22]. In MCA, various approaches are used to classify, compare, and select the most appropriate alternatives with respect to the given criteria, such as the Analytical Hierarchy Process (AHP), Multi-Attribute Utility Theory (MAUT), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Dominance-based Rough Set Approach (DRSA), and outranking methods such as Elimination and Choice Expressing the Reality (ELECTRE) [20,23]. These approaches are the most widely used MCDA tools in sustainability-related research, as reported in various publications. MAUT is a performance aggregation-based approach, which requires the identification of utility functions and weights for each attribute, which can then be aggregated in a unique synthesizing criterion. The AHP is another approach of the first performance aggregation-based approaches, and it was introduced by Saaty [24] with the aim of evaluating criteria based on an absolute scale. The main idea of the TOPSIS technique is that the preferred alternative is the one that is the closest to the positive ideal solution and the furthest from the negative ideal solution; the positive ideal solution is formed as a combination of the best points of each criterion, and the negative ideal solution is a combination of the worst points of each criterion [25]. This technique is only can be applied for the numerical dataset where the importance weights of the criterion are known or defined, based on the experts. The DRSA is a new technique that can classify choice and rank alternatives; it is based on an information distributed in a table whose rows are defined as alternatives, and where the columns are divided into conditions or criteria that are needed to assess the alternatives [20,26]. ELECTRE are preference aggregation-based methods, working on pairwise comparisons of the alternatives; they are known as outranking approaches because they purpose to assess whether alternative X is at least as good as (outranks) Y [20,23,26].

The most common MCA methods that appear to be widely used in the environmental management is the AHP, followed by MAUT, due to its simplicity, accessibility, and user-friendly nature, while the least commonly applied is TOPSIS [20,23,25].

Sustainability criteria are applied in MCA to deliver a measurement system, and they can indicate the requirements or standards for achieving sustainable services in a specific context. Indicators are measurements or assignments of values that indicate the accomplishment of sustainability criteria [27]. Most of the common environmental indicators include energy use, emissions, and pollutant removal. In terms of economical indicators, capital costs, operational costs, and resource recovery are frequently used. Despite the progressive development of both environmental and economical indicators, social indicators are usually ignored because of their difficulties in measurement and quantification [16,28–30]. However, social indicators can be translated into a quantitative format using a points-based scale [31,32], and using willingness to accept (WTA) and willingness to pay (WTP) indicators [33,34].

Previous studies have integrated all sustainability criteria when assessing wastewater treatment alternatives [29–31]. As a common multi-criterion issue, selecting among sustainability criteria is crucial to obtaining a final selection between alternatives [35]. As a result, the calculation of weights processes has been established to aggregate indicators into a composite index for each alternative. Gherghel et al. [36] have applied a Weighted Sum Model (WSM) to aggregate the performance of six criteria, in order to distinguish different wastewater treatment systems [36]. Molinos-Senante et al. [31] have used a 'Global Sustainability Indicator' to compare seven wastewater treatment alternatives according to environmental, social, and economic criteria [31]. These previous works illustrated that a composite indicator can be a practical and reliable method to integrate multiple sustainability criteria.

In general, sustainability assessment methods are widely applied and studied in the research and academic sector, but they are limitedly applied in the practical decision-making process, especially in the water and wastewater sectors.

4. Methodology

The methodology used in this research was adapted from Ling et al. [16] and divided into five steps, as described in Figure 1. Firstly, understanding the local context; secondly, the construction of decision hierarchy; thirdly, the calculation of weights; fourthly, score aggregation and ranking of the treatment alternatives, and finally, checking the sensitivity analysis and determining the critical indicators [16]. The development process was applied to compare three wastewater treatment alternatives that can be sustainable and suitable for the selected case study.

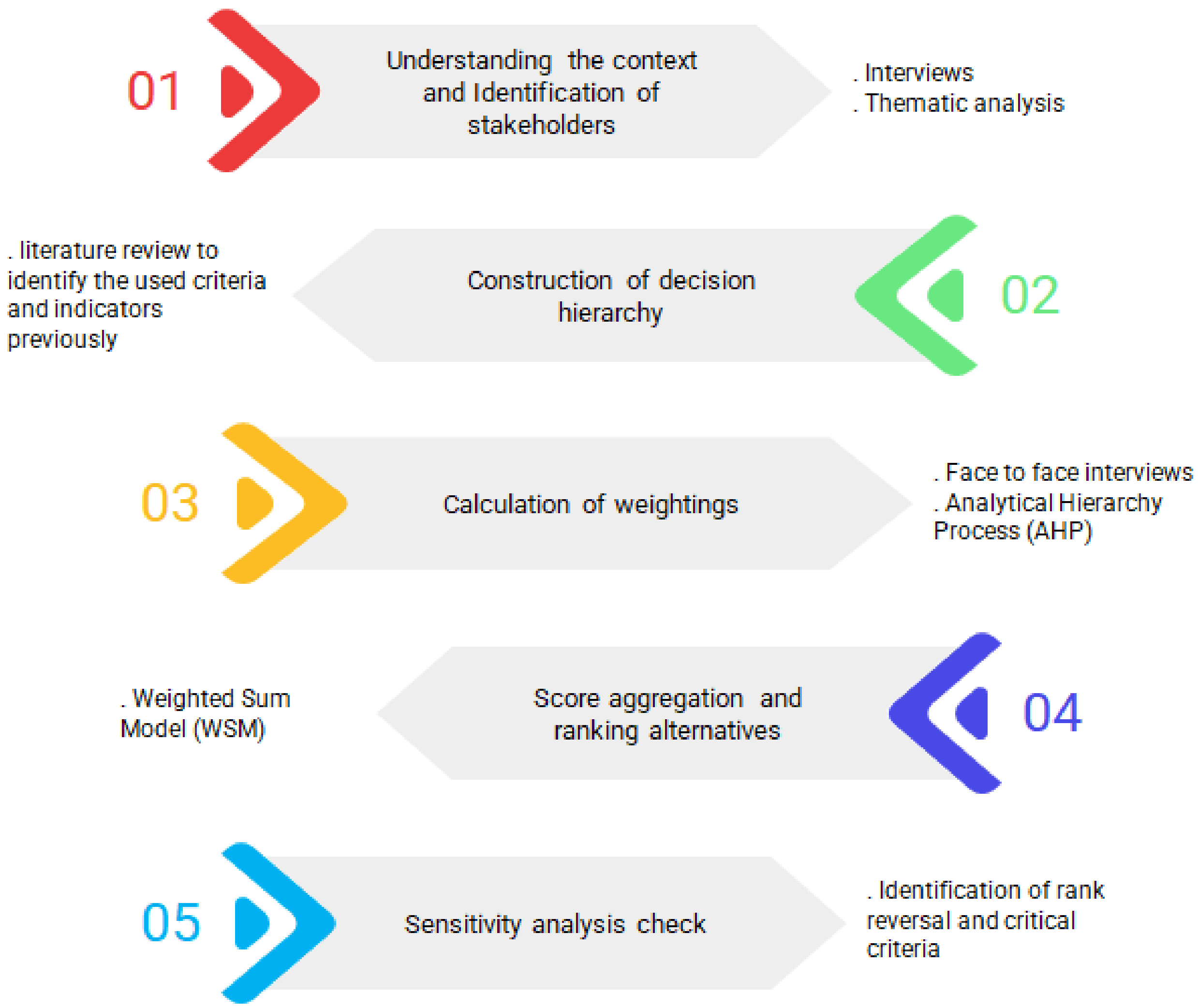

Figure 1. The steps of developing the MCA.

4.1. Understanding the Context and Identification of Stakeholders

As the first step, it is important to understand the context in detail from different aspects; the environmental, social, and economical conditions that are essential for the project development. Investigation into the town and the community has been initially performed in order to have a general view of the current situation, and also to identify the gaps and the required awareness among the population about the problem, in order to connect the community with the project, as well as preliminarily identifying some indicators.

The second step was the governance assessment aiming to understand the legal framework, the local legislation and policies, and the reuse standards. This step also identifies the governmental stakeholders, their level of importance, and their roles within the project. The next step was the socio-economic analysis with a main aim of tailoring the project and the strategy to the specific selected context. Then, a technical and economic feasibility study were done to identify the cost-effective solution of the plant, and the possible technical options. As a final step, preliminary environmental and social impact assessment analyses were investigated to identify the possible negative environmental and social impacts of the project.

Stakeholder analysis has been carried out to identify the main stakeholders in the project, and their role and impacts, the analysis step has been followed by semi-structured interviews that were conducted with the stakeholders as an initial step to understand the current practices and challenges of selecting the wastewater treatment technologies for the selected case study. The interviews also helped to engage with stakeholders during the development process of the MCA, and to collect their feedback about the tool.

Semi-structured interview guidelines prepared by Laforest et al. [37] were pursued with the selected stakeholders. The interviews were conducted anonymously; each interview lasted an hour, with complete confidentiality of the answers and of the gathered data and information; finally, a validation of the answers with the respondent and an authorization for using the collected data were collected.

4.2. Construction of a Decision Hierarchy

The construction of a decision hierarchy is critical for developing a representative and successful MCA assessment in order to achieve the objective of the MCA. The study firstly considered a literature review and desk study step to collect indicators that have been used to evaluate wastewater treatment technologies from previous similar studies. Table 1 below summarizes the main indicators used for similar analysis. This list was further reviewed and discussed with stakeholders, and then a final list of criteria and indicators was proposed based on the priorities mentioned in the interviews.

Table 1. Common criteria and indicators to assess wastewater treatment technologies from literature review and previous studies.

Criteria	Indicator	References
Environmental	Soil and land contamination *	[16,38]
	Greenhouse gas emission or carbon footprint *	[16,38,39]
	Environmental impacts	[16,40,41]
	Nonrenewable raw materials	[16,40]
	Biodiversity	[42]
	Durability	[43–45]
	Stability *	[28,38,43,45]

Table 1. *Cont.*

Criteria	Indicator	References
Institutional	Availability of local capabilities and local technical capabilities within the institution *	[40,42,46]
	Compatibility with the local strategies, standards *	[42]
Technical	Pollutant removal potentials	[16,28,30,31,38,39,47]
	Amount of sludge produced *	[28,30,38,48]
	Generated by-products *	[16,28,38,48]
	Ease of implementation	[16,28,44]
	Ease of operation* (ordinary and extraordinary maintenance)	[28,44,48]
	Availability of local materials	[49–51]
	Possibility for future expansion *	[51–53]
	Small scale technologies used	[16,54]
Social	Public acceptance—compatibility with general service level *	[16,55]
	Odor and noise impact *	[16,28,44]
	Provision of aesthetic and green places	[42,55]
	Community participation and job opportunities *	[16,31]
	Respect of local culture	[16,28,39,56]
	Health of the community	[28,39,57,58]
	Willingness to pay *	[53,58–60]
	Visual impact *	[44,53,56,58–60]
Economic	Construction/capital costs *	[28,45,58,61,62]
	Operation and maintenance costs *	[28,31,39]
	Land cost	[28,31,39,42,47]
	Local market incentive	[52,53]
	Treated WW reuse *	[40,63,64]
	Land requirement *	[16,28,30,39]
	Chemical requirements	[16,65]
	Energy requirements *	[28,31,65]

* Also suggested by local stakeholders.

4.3. Calculations of Weights

4.3.1. Weighting Allocation Using the AHP

The AHP, developed by Thomas Saaty, R.W [24], was selected for this study because of its simplicity of application and its developed theoretical basis [24]. AHP is the most widely used in MCA approaches according to the number of its applications [66,67]. The procedure of AHP is based on three components: the anatomy of the problem as a hierarchical structure, pairwise comparisons, and calculation of weights [68]. Pairwise comparison is the main task of AHP. The main question to be asked is 'how important is criteria X compared to criteria Y?' Each comparison determines the direction and the degree of importance between two indicators, using a semantic scale, as described in Table 2. For example, a scale number of 5 referring to criteria X is strongly more important than criteria Y, whereas 1/5 refers to a reversed preference direction.

Table 2. The semantic scale for pairwise comparison in AHP, adopted from Saaty, R.W [24].

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption
1.1–1.9	If the activities are very close	May be difficult to assign the best value, but when compared with other contrasting activities, the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities

For opinions and ratings collection, stakeholders were invited to a semi-structured interview to complete pairwise comparisons between criteria and indicators. Each stakeholder provided his/her preference opinion through a series of pairwise comparisons questions.

The comparisons were carried out at the first level (criteria) of the hierarchy, and then at the second level (indicators) of the hierarchy under each criteria. A reciprocal matrix of $m\ X\ m$ was created based on m number of criteria/indicators to be compared, as described in Equation (1).

$a_{1,\mathrm{m}}$ indicates the opinion made between criteria number 1 and the $m_{\text{-th}}$ criteria, etc. In total, an $m\ (m-1)$ number of comparisons are required per each matrix, given the property of reciprocity in AHP. An $(m + 1)$ number of matrices is required to calculate the weights for each stakeholder (1 for comparisons between all criteria at the first level, and m for the comparisons between indicators within each criteria).

$$A = \begin{bmatrix} 1 & a_{12} & a_{13} \\ a_{21} = 1/a_{12} & 1 & a_{23} \\ a_{31} = 1/a_{13} & a_{32} = 1/a_{23} & 1 \end{bmatrix} \tag{1}$$

The comparison matrix must be normalized to obtain the weight of each indicator. The method starts with the summing of each column as:

$$a_{columnj} = a_{1j} + a_{2j} + a_{3j} \tag{2}$$

and the normalized matrix is calculated by dividing each element by the sum of its column [16,24]

$$A = \begin{bmatrix} 1/a_{column1} & a_{12}/a_{column2} & a_{13}/\ a_{column3} \\ a_{21}/a_{column1} & 1/a_{column2} & a_{23}/\ a_{column3} \\ a_{31}/a_{column1} & a_{32}/a_{column2} & 1/\ a_{column3} \end{bmatrix} \tag{3}$$

Then, MATLAB was used to calculate the eigenvalues and eigenvectors for the normalized matrix. The principal eigenvectors that correspond to the highest eigenvalue have been considered to represent the final weights of the indicators. Mathematically, the eigenvectors are being calculated by averaging across the row of the normalized matrix, and the eigenvalue is obtained by summation of the products between each element of the eigenvector and the sum of the columns of the matrix. However, MATLAB has been used to calculate both eigenvectors and eigenvalues, in order to guarantee the accuracy of the calculations. At the end, the eigenvector obtained from MATLAB needs to be normalized to represent the final weights, and this is given by dividing individual value of the eigenvector in each row A_r by the summation of the eigenvector values, as in Equation (4) [16,69]:

$$w_r = \frac{A_r}{\sum_{m=1}^{j} A_r} \tag{4}$$

The normalized eigenvector w_r represents the weight of the indicator in a specific pairwise comparison [16,24,69].

To verify the correctness of the procedure, the consistency ratio (*CR*) was calculated for the entire comparison group to determine the consistency levels of judgements and opinions from stakeholders [24]. Responses with *CR* values of greater than 0.1 were revised, and when *CR* remained greater than 0.1, the responses were excluded from the further aggregation of the group weightings. The 10% is tolerated because the priority of consistency to obtain a coherent explanation of a set of facts must differ over an order of magnitude from the priority of inconsistency, which is an error in the measurement of consistency. Thus, on a scale ranging over 0–1, the consistency ratio should not exceed 0.10 [24]. The consistency ratio (*CR*) is given by:

$$CR = \frac{CI}{RI} \tag{5}$$

where *CI* is the consistency index and *RI* is the random index.

The *CI* is determined by:

$$CI = \frac{\lambda - n}{n - 1} \tag{6}$$

where n is the number of the parameters in the comparison, criteria, or indicators; and λ is the principal eigenvalue obtained from MATLAB, and represents the summation of the product between the sum of each column $a_{columnj}$ and the corresponding eigenvector w_r.

The random index (*RI*) is a fixed value related to the number of indicators or criteria present in the comparison. Table 3 below indicates the *RI* values according to the literature [16,24,70].

Table 3. Random Index RI values.

N° of Indicators	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

The value output of *CR* is compared to the fixed reference value 0.10, with this meaning:

$$if\ CR < 0.1$$

Then the procedure is consistent, and the calculated weight can be used

$$if\ CR > 0.1$$

Then the procedure is inconsistent, the calculated weight can't be used. The procedure needs to be rechecked.

4.3.2. Group Weightings

Every stakeholder made one set of responses and one weighting profile (normalized eigenvectors). A group of weightings is required to represent the overall responses on the importance of the selected criteria and the indicators. According to the literature, several ways of developing the group weighting can be used: (i) sharing, refers to the exchange of opinions and preferences among all stakeholders, and then the selection of one input for AHP calculation; (ii) comparing, refers to the comparison of weightings developed from individual preferences and deciding which set of weights is the most representative; or (iii) aggregating, means the mathematical aggregation and collection of individual weightings [16,71]. In this study, mathematical aggregation was considered as being more suitable due to the time limitation, the availability of the stakeholders, and the COVID-19 emergency situation, where social distancing conditions were still required when this study was conducted. The geometric mean was performed to aggregate individual weightings into a group weighting as:

$$\overline{w_k^q} = \sqrt[q]{\left(\prod_{n=1}^{q} w_k\right)} = \sqrt[q]{w_k^1 w_k^2 \ldots w_k^q} \tag{7}$$

where $\overline{w_k^q}$ is the aggregated group weight for the k_{-th} criteria or indicator, while q represents a number of stakeholders; similar to the normalization of weights from a reciprocal matrix using Equation (4), the aggregated group weights were normalized so that the sum of all criteria is equal to 1.

4.4. Score Aggregation and Options Ranking

Wastewater treatment alternatives have been selected for the application of the criteria hierarchy and group weightings. The name and location of the wastewater treatment plant (WWTP) was mentioned before in the study and was clearly explained to the stakeholders. The proposed WWTP was designed to serve a population of approximately 15,000. The following three treatment alternatives were considered for the selected case:

1. Activated Sludge Process (ASP),
2. Stabilization Ponds Process (SP),
3. Constructed wetlands— (French constructed wetlands) FCW.

The technologies have been selected based on the most commonly used technologies in Jordan. Jordan has 33 centralized WWTPs (27 WWTP used ASP, and six WWTP used SP) while the third option, FCW, was proposed by the donor and the implementation partner as they were willing to evaluate using FCW as an application of NBS in the country. Several aspects have led the implementation partners to propose FCW for Al Azraq, as they have previously implemented several types of CWs, including FCW, under the same environment and climate conditions in the Middle East, the availability of local materials, especially the tuff in Al Azraq town, the availability of the land area, and the simplicity of operating the FCW. The treated wastewater will be used in fodder crops and uneatable agriculture according to the Jordanian standards 839–2021 [72]; and the selected alternatives are able to treat the wastewater to the selected levels, and this is illustrated through different WWTPs using the same technologies in Jordan and in the neighboring countries. The stakeholders validated the suitability of the selected alternatives for the town.

Figure 2 below shows the basic treatment process outlines of the three alternatives to be compared. The proposed treatment processes started from pretreatment to sludge treatment and disposal. Detailed mechanical, chemical, and biological process designs are not included, as the technical aspect of each wastewater treatment process is not discussed in this study.

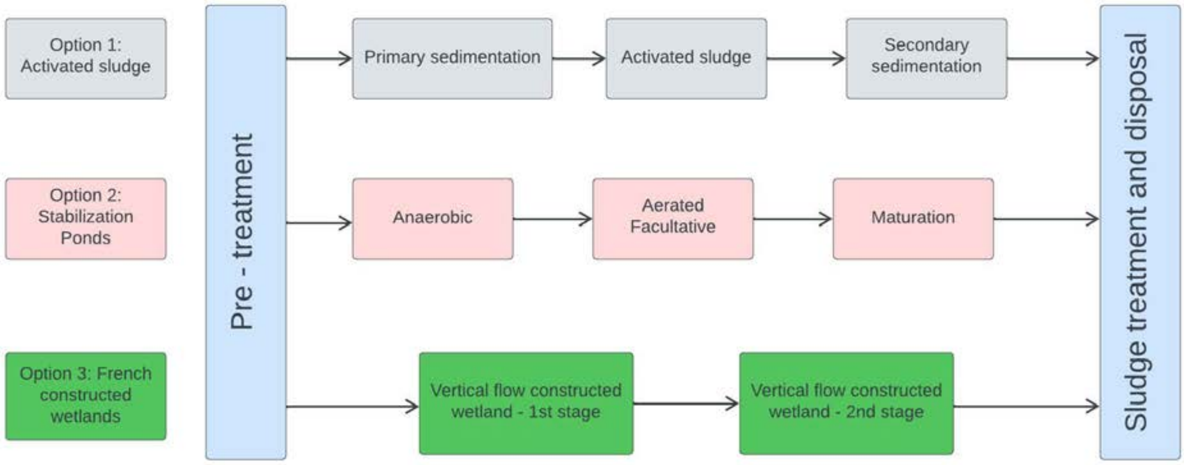

Figure 2. Basic process design for the three selected treatment alternatives. This study considered pretreatment, secondary and sludge treatment, and disposal, in order to meet the Jordanian standards for reuse, JS893–2021.

The criteria hierarchy and weightings developed in this study have been used to assess the overall scoring of each technology. The assessment of each indicator for each technology was provided in the format of performance ratings using a 5-point scale based on stakeholder's opinions and judgments. Then, a Weighted Sum Model (WSM) was used to generate the performance ratings of indicators ($v_1, v_2, \ldots, v_n$) and their corresponding weights ($w_1, w_2, \ldots, w_n$) into a composite score **Si** for the ***i*-th** option, as:

$$Si = \sum_{i=1}^{n} w_n v_n = w_1 v_1 + w_2 v_2 + \cdots w_n v_n \tag{8}$$

4.5. Sensitivity Analysis Check

It is a common practice in AHP to analyze the sensitivity of the composite score and the ranking of options to potential changes in criteria weights. This study included two elements of sensitivity analysis. First, identifying the most critical indicator by calculating the minimum changes required in weights to cause a rank reversal. As the aim of this case study is to identify the best option, only the rank reversal between the top two options were considered. The steps for identifying the most critical indicator were based on the theory developed by Trianaphyllou and Sanchez [73], and were used and illustrated by Ling et al. [16]. The theory said that if the $i_{\text{-th}}$ option is the best and the $j_{\text{-th}}$ option is the second-best according to their composite scores ($S_i > S_j$), then the minimum change $\delta_{k.i.j}$ in the weight of indicator C_k to cause a rank reversal between i and j can be calculated. If the performance of the $j_{\text{-th}}$ option is better than the $i_{\text{-th}}$ option with respect to the $k_{\text{-th}}$ indicator ($v_{jk} > v_{ik}$), then

$$\delta_{k,i,j} < \frac{S_j - S_i}{v_{jk} - v_{ik}} \tag{9}$$

If the performance v of the $i_{\text{-th}}$ option is better than the $j_{\text{-th}}$ option with respect to the $k_{\text{-th}}$ indicator ($v_{jk} < v_{ik}$), then

$$\delta_{k,i,j} > \frac{S_j - S_i}{v_{jk} - v_{ik}} \tag{10}$$

Additionally, the relative minimum change $\delta_{k.i.j}$ can also be expressed as:

$$\delta^{\backslash}_{k,i,j} = \left| \frac{\delta_{k,i,j}}{w_k} \right| \times 100\% \tag{11}$$

$\delta_{k.i.j}$ may not have a feasible value. In other words, it may be impossible to reverse the existing ranking of the alternative $i_{\text{-th}}$ and $j_{\text{-th}}$ by making changes on the current weight of criterion. This situation occurs when the value of $|\delta_{k.i.j}|$ is greater than weight value of indicator k [73].

The second element used to check the sensitivity in this research is assume that the selected performance indicators have equal importance for all the stakeholders. Equally weighted criteria are a common situation, against which the sensitivity of the results is tested. In this case study, the selected performance indicators are 16, and thus, each one has a weight factor of 100%/16 = 6.25%; considering the unified weights for indicators and the composite scores from stakeholders, the final options ranking will be checked and compered to the ranking resulting from the MCA [74,75].

5. Results

5.1. Semi-Structured Interview and Thematic Analysis

Ten stakeholders from different sectors (government, academia, WWTP designers, WWTP operator donors, international NGOs, and local NGOs) participated in the study and the interview process. Table A1 in Appendix A provides more details about the stakeholders' profiles. Firstly, the stakeholders evaluated and validated the suggested and proposed criteria and indicators, which is a summary of the thematic analysis and results from the stakeholders' interviews. Secondly, the stakeholders validated and confirmed the selected technology alternatives, which have previously been illustrated in Figure 2.

5.2. Construction of a Decision Hierarchy

According to the indicators summarized from the literature and listed in Table 1, and from the results of the semi-structured interviews, the proposed criteria hierarchy for assessing and selecting wastewater treatment technology are illustrated in Figure 3, while the detailed definition of each indicator are summarized in Table A2 in Appendix A.

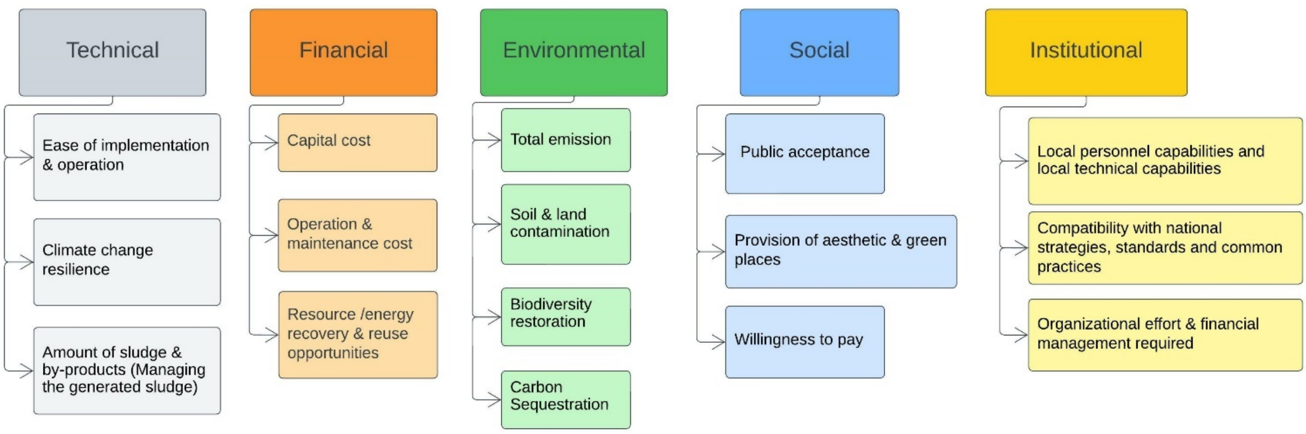

Figure 3. Proposed criteria and indicators hierarchy for the sustainability assessment of the wastewater technology for this study.

The hierarchy consists of two levels. The first level represents the five aspects of sustainability, and the second level illustrates the assessment indicators under each criteria.

Sustainability criteria were commonly used in the previous studies to assess treatment technologies, and the use of these criteria was validated by the stakeholders [16,28,39,44]. This is considering that climate change resilience under the technical sustainability was suggested by stakeholders in order to have a resilient technology that can provide the same treatment efficiency under different climate conditions. The management, treatment, and disposal of sludge created a problem in Jordan, and thus, "Amount of sludge and by-products—managing he generated sludge" has been selected as a technical indicator, besides the ease of implementation and operation. Resource recovery and the final reuse of the products have the priority according to the Jordanian situation to sustain the long-term operation under the financial sustainability criteria. The environmental sustainability has a special situation, since the project will be located within a Ramsar site where restoring the biodiversity has priority and carbon sequestration as well, in order to minimize the total emission while protecting the soil and the lands. For social sustainability and based on onsite evaluation, it was found that providing an aesthetic place and a green area are important indicators for the community, and will enhance the possibility of the willingness to accept and the willingness to pay to have the service. Finally, the institutional sustainability, as the selected technology, has to meet the local standards of operation and maintenance; it should be compatible with the framework of the responsible institute, and should be within their technical and financial capacities.

5.3. Weightings

The weights of each indicator that resulted from AHP from 10 stakeholders and the aggregated group weights are summarized in Table 4 below. According to the results of the group weights, 'Public acceptance' had the highest weight (0.204), reflecting the importance of social acceptance for similar projects and interventions. Several stakeholders have illustrated during the semi-structured interviews that meeting social sustainability and community acceptance play a main role in having sustainable wastewater technology, and it is always a priority when selecting the wastewater treatment system.

Table 4. Individual weightings of the 10 stakeholders, aggregated group weightings on the indicators, and the final ranking of group weights.

Criteria	Indicators	Stakeholders										Geom Mean	Weight	Rank
		1	2	3	4	5	6	7	8	9	10			
Technical	easiness	0.23	0.09	0.11	0.06	0.18	0.05	0.07	0.14	0.07	0.07	0.09	0.1	3
	climate change	0.05	0.02	0.04	0.03	0.04	0.01	0.02	0.02	0.01	0.01	0.02	0.02	14
	sludge	0.06	0.03	0.02	0.01	0.04	0.02	0.02	0.05	0.03	0.03	0.03	0.03	13
Financial	capex	0.04	0.11	0.03	0.02	0.03	0.03	0.02	0.02	0.06	0.06	0.04	0.04	10
	opex	0.12	0.32	0.11	0.2	0.18	0.16	0.16	0.1	0.15	0.25	0.16	0.18	2
	recovery	0.07	0.08	0.02	0.06	0.03	0.07	0.05	0.04	0.04	0.07	0.05	0.05	6
Environmental	emission	0.02	0.02	0.04	0.05	0.02	0.04	0.08	0.05	0.06	0.02	0.04	0.04	9
	contamination	0.04	0.02	0.03	0.04	0.03	0.03	0.03	0.01	0.03	0.04	0.03	0.03	12
	biodiversity	0.01	0.01	0.07	0.02	0.01	0.02	0.02	0.02	0.01	0.01	0.02	0.02	16
	carbon	0.01	0.04	0.07	0.05	0.03	0.04	0.04	0.02	0.02	0.01	0.03	0.03	11
Social	acceptance	0.13	0.11	0.2	0.24	0.18	0.17	0.26	0.32	0.21	0.14	0.19	0.2	1
	aesthetic	0.05	0.02	0.12	0.09	0.1	0.14	0.06	0.08	0.12	0.05	0.07	0.08	4
	willingness	0.03	0.05	0.05	0.06	0.05	0.11	0.1	0.04	0.06	0.03	0.05	0.06	5
Institutional	capability	0.02	0.02	0.04	0.01	0.01	0.03	0.02	0.01	0.03	0.03	0.02	0.02	15
	compatibility	0.08	0.03	0.03	0.03	0.04	0.05	0.02	0.03	0.06	0.07	0.04	0.04	7
	management	0.05	0.03	0.03	0.03	0.03	0.04	0.02	0.05	0.03	0.11	0.04	0.04	8

The operational cost has been ranked second, with a weight of (0.181). This was followed by the ease of implementation and operation (0.103), and of having aesthetic and green areas (0.080). Although the capital cost is also important, the capital costs were funded through an international donation for the Al Azraq project. It is worth mentioning that climate change resilience, local capabilities, and restoring biodiversity indicators have the least importance and have been ranked 14, 15, and 16, respectively. At the first level of the hierarchy, the weights for each sustainability criteria were obtained; the social criteria (0.341) had the highest weight, followed by the financial criteria (0.268), then the technical criteria (0.154) and environmental criteria (0.126), and finally, the institutional criteria (0.110), as summarized in Table 5.

Table 5. Individual weightings of the 10 stakeholders, aggregated group weightings on the criteria, and the final rankings of group weights.

Criteria	Stakeholders										Geom Mean	Weight	Rank
	1	2	3	4	5	6	7	8	9	10			
technical	0.35	0.13	0.16	0.09	0.27	0.09	0.11	0.21	0.11	0.11	0.14	0.15	3
financial	0.22	0.50	0.16	0.28	0.24	0.26	0.23	0.16	0.25	0.38	0.25	0.27	2
environmental	0.08	0.10	0.21	0.16	0.09	0.13	0.17	0.10	0.12	0.08	0.12	0.136	4
social	0.21	0.19	0.37	0.39	0.32	0.42	0.42	0.43	0.39	0.22	0.32	0.34	1
institutional	0.14	0.08	0.10	0.07	0.08	0.11	0.07	0.10	0.12	0.22	0.10	0.11	5

Although previous studies and literature showed that financial and technical criteria could have the highest scores compared to other criteria, Ling et al. [16] highlighted that comparing weighting profiles across different studies does not make sense, because decision priorities and contexts vary among studies [16]. The final weights in this case study were presented to the participated stakeholders for their feedback. All stakeholders were satisfied with the results of the group weights.

The consistency ratios have been checked for all pairwise comparisons resulting from the AHP for the 10 stakeholders. The results showed that the pairwise comparisons are within the acceptable consistency ratio, as illustrated in Table 6 below.

Table 6. Consistency ratios check for pairwise comparisons of the 10 stakeholders.

Stakeholders	CR Check	Criteria	Technical	Financial	Environmental	Social	Institutional
1	CR	0.089	0.025	0.002	0.069	0.003	0.008
	Check	ok	ok	ok	ok	ok	ok
2	CR	0.09	0.021	0.093	0.057	0.005	0.000
	Check	ok	ok	ok	ok	ok	ok
3	CR	0.08	0.074	0.081	0.086	0.046	0.046
	Check	ok	ok	ok	ok	ok	ok
4	CR	0.09	0.074	0.028	0.057	0.081	0.008
	Check	ok	ok	ok	ok	ok	ok
5	CR	0.095	0.005	0.021	0.09	0.008	0.046
	Check	ok	ok	ok	ok	ok	ok
6	CR	0.078	0.005	0.030	0.068	0.046	0.046
	Check	ok	ok	ok	ok	ok	ok
7	CR	0.09	0.093	0.028	0.082	0.016	0.000
	Check	ok	ok	ok	ok	ok	ok
8	CR	0.06	0.074	0.003	0.044	0.056	0.046
	Check	ok	ok	ok	ok	ok	ok
9	CR	0.07	0.063	0.046	0.032	0.008	0.000
	Check	ok	ok	ok	ok	ok	ok
10	CR	0.098	0.002	0.025	0.057	0.093	0.046
	Check	ok	ok	ok	ok	ok	ok

5.4. Score Aggregation and Final Ranking

The group weights resulting from the previous step were applied to the performance ratings of indicators for a score aggregation (as described previously, each stakeholder scored the selected technologies on a scale from 1 to 5 to indicate its performance under each indicator). Table 7 below summarizes the average performance ratings of each indicator for each technology option, as provided by the stakeholders.

Table 7. The average performance ratings of each indicator among 10 stakeholders on a (1–5) scale; 1 refers to the poorest performance of that indicator, while 5 refers to the best.

Criteria	Indicators	AS	SP	FCW
Technical	Ease of implementation and operation	2.7	4.4	4.2
	Climate change resilience	3.5	2.8	3
	Amount of sludge and by-products (Managing the generated sludge)	1.6	2.7	3.4
Financial	Capital cost	1.2	3.4	3.3
	Operation and maintenance cost	1.4	3	3.8
	Resource/energy recovery and reuse opportunities	3.1	2.2	2.8
Environmental	Total emission	1	3.2	4.2
	Soil and land contamination	1.8	2.7	2.9
	Biodiversity restoration	1.4	2.5	4.6
	Carbon sequestration	1	1.7	4.8
Social	Public acceptance	2.4	1.8	1.6
	Provision of aesthetic and green places	1	1.6	3.9
	Willingness to pay	1.7	1.8	1.9
Institutional	Local personnel capabilities and local technical capabilities	4.1	4	3.4
	Compatibility with national strategies, standards, and common practices	4.4	4	3.2
	Organizational effort and financial management required	2.1	2.6	2.4

Firstly, the scores of the indicators were aggregated into each criteria according to the hierarchy in Figure 3. Secondly, further aggregation into a composite score for each technology option was described in Figure 4. Figure 4 allows decision makers and stakeholders to understand and to rank the options based on their total scores, and to identify the best sustainable technology under each sustainability criterion.

- Overall: The FCW option was scored as the best option for this case study, and based on its composite score (3.13), followed by SP (2.67), and finally, the AS (2.07).
- Institutional criteria: FCW has the highest scores for most of the criteria, except the institutional criteria, where SP and AS had higher scores (0.37), while FCW scored (0.32).
- Social: FCW scored (0.75) followed by AS (0.67), and lastly, SP, with (0.6).
- Environment: FCW scored (0.49), and that indicated the difference between the conventional treatment systems and the nature-based solutions, such as FCW.
- Technical: FCW and SP had the same score (0.6), while the AS scored (0.41) due to the complexity of operating AS.
- Financial: FCW scored (0.96), followed by SP (0.49), and then AS (0.46).

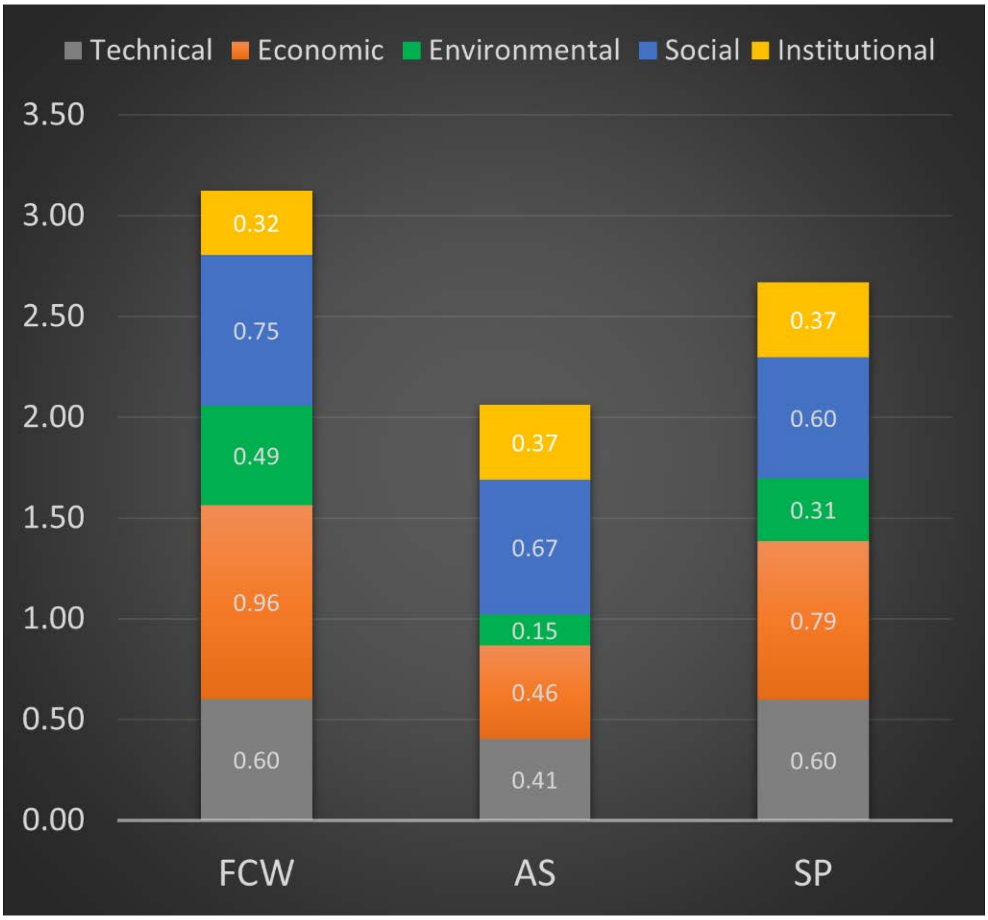

Figure 4. Scores of three treatment alternatives for each assessment criteria. A higher score means a greater performance.

5.5. Sensitivity Analysis Check

The first element of the sensitivity analysis check was to calculate the minimum change in the group weight of each indicator to cause a rank reversal between the top two options, using Equations (10)–(12). Table 8 shows the calculated minimum weight change δ that is required to determine if the indicator is critical or not; the calculation shows that all indicators are robust and are not sensitive; in other words, any changes in the indicator's weights will not change the overall options ranking. The absolute change and the relative change that all indicators can withstand for a value change in their weights without causing a rank reversal for this case study.

For the second check using equally weighted criteria, equal weights have been applied to test the sensitivities of the results. In this case study, the selected performance indicators are 16, and thus, each indicator has a weight factor of $(1/16) \times 100\% = 6.25\%$, considering the unified weights for the indicators and the composite scores from the stakeholders. The results showed that while the overall scores for all the treatment options increased, the final options ranking was not affected. As illustrated in Figure 5 below, this method provided further illustration of the robustness of the selected indicators.

Table 8. The minimum changes required in indicator weights to cause a rank shift between the best option (FCW) and the second-best option (SP).

Indicators	Group Weight	Absolute Change $\delta_{k.i.j}$	Relative Change
Ease of implementation and operation	0.103	2.3	2240%
Climate change resilience	0.023	2.3	10,092%
Amount of sludge and by-products (managing the generated sludge)	0.030	0.66	2180%
Capital cost	0.039	4.6	11,937%
Operation and maintenance cost	0.181	0.58	318%
Resource/energy recovery and reuse opportunities	0.052	0.77	1465%
Total emission	0.040	0.46	1161%
Soil and land contamination	0.030	2.3	7564%
Biodiversity restoration	0.019	0.22	1140%
Carbon sequestration	0.031	0.15	475%
Public acceptance	0.204	2.3	1126%
Provision of aesthetic and green places	0.080	0.2	250%
Willingness to pay	0.058	4.6	7867%
Local personnel capabilities and local technical capabilities	0.022	0.77	3458%
Compatibility with national strategies, standards, and common practices	0.045	0.58	1289%
Organizational effort and financial management required	0.043	2.3	5399%

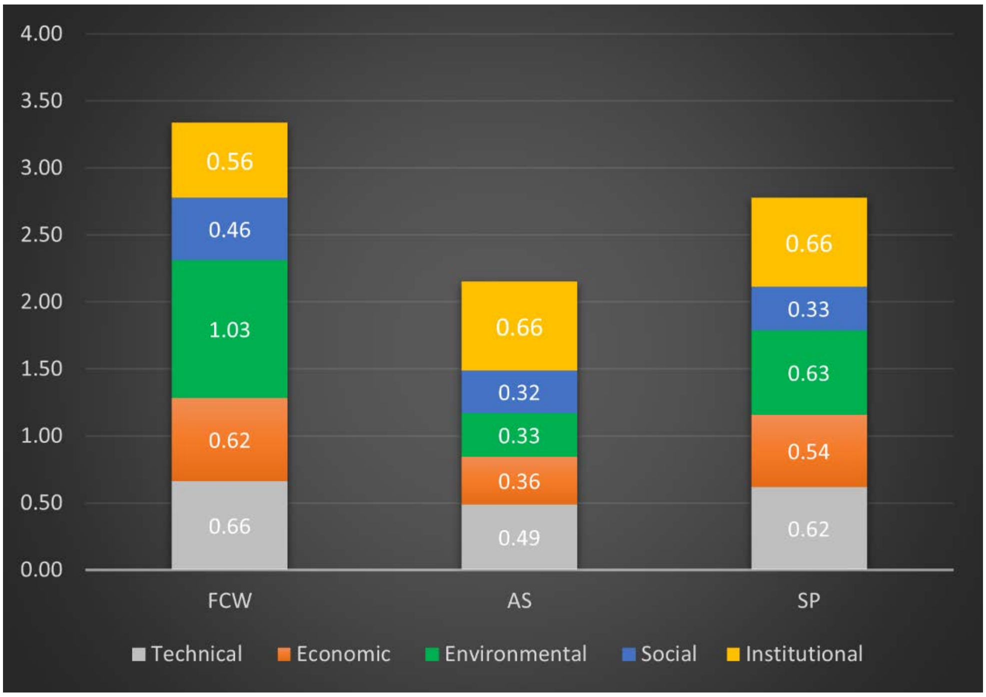

Figure 5. Scores of three treatment options after unifying the indicators weights. A higher score means a greater performance.

6. Discussion

In this study, sustainability criteria have been used for evaluating different treatment technologies. Each criteria has been divided into indicators that summarize the importance of the criteria. Although the sustainability criteria have been widely and effectively used for similar comparisons, the number of selected indicators is limited, due to the accuracy of the MCA process. Therefore, selecting indicators are crucial in MCA. In this study, the criteria and indicators have been selected after a deep understanding of the local context, conducting several site visits, and engaging stakeholders while implementing the MCA tool. From the local context, it was understood that for similar cases where the population count is moderate (5000 to 15000), the operators of the treatment plant are critical; usually, wastewater treatment plants are operated by the MWI or private companies, while the proposed operation scenario for this case study is to be operated by the local municipality. Due to that, the ease of implementation, maintenance, and management of the generated sludge are highly important technical indicators for selecting treatment technology. That operation scenario has highly affected the selecting process; not just the technical indicators, but also the financial and social indicators, such as the operation and maintenance costs, and resource recovery/reuse opportunities, in order to integrate suitable business models and socio-economic plans. The importance of environmental indicators has a higher level of importance; some indicators are matching the national climate change adaptation plan, such as carbon sequestration and total emissions indicators, while other indicators are linked with the social criteria, such as the provision of aesthetic places indicators. However, some indicators were not included in this study, such as odor problems and attracting insects and mosquitoes; these indicators might affect the social acceptance, but according to stakeholders, these problems can be avoided by selecting a proper location for the treatment plant.

Although including stakeholders is a key factor, this study found that introducing a new assessment method is challenging. Firstly, the availability of the stakeholders was an obstacle, and it should be considered carefully when developing the MCA. Ideally, engaging with as many stakeholders as possible would be useful for developing representative results. However, stakeholders were often occupied and not available. To overcome this challenge, stakeholders have been communicated through the implementing partners and the donor of the project. Secondly, meeting the stakeholders separately helped to overcome the authority segregation problem in the Jordanian wastewater sector, Thirdly, practicing AHP and pairwise comparison was confusing for some stakeholders, conducting MCA and pairwise comparison with stakeholders through face-to-face interviews helped in solving their confusion, and regular consistency ratio checks have been carried out immediately to avoid and to minimize the possible errors. Most of the stakeholders expressed their interest in AHP and the composite score approach after seeing the results and figures.

7. Limitations and Future Development

Although the sensitivity analysis for this research did not show any possibilities of reverse ranking, the pairwise comparisons can usually be sensitive to the number of alternatives to be compared, and the changes in weights, which might lead to rank reversal. Therefore, the sensitivity analysis is crucial to determining the critical criteria and its impact on the final ranking.

While the methodology for the MCA and AHP can be the same, the indicators and criteria can be different for another case study within the same country. This means that if we apply the same methodology and with the same indicators for another case study in Jordan, it might lead to different technology ranking. However, this can be considered as a benefit, since the flexibility of selecting indicators helps with obtaining better results for each specific case.

The Saaty scale in AHP (1–9 point) was difficult to use for stakeholders who were unfamiliar with the method. The scale can be considered as long scale; therefore, extreme values such as 9 or 8 were rarely used, and it was difficult for some stakeholders to understand the definition of the scale. For that, the reduced scale is recommended, and will be considered for future similar applications

While the mathematical part is relativity simple, achieving the consistency ratio limit was challenging. The consistency ratio was calculated since it is also linked with using the (0–9 point) scale; therefore, stakeholders were carefully scored for the indicators.

Further implementations of the sustainability assessment tools will provide accumulative knowledge and a database to support the decision-making process in the Jordanian wastewater sector.

Further research can consider different indicators listed in order to create a wider vision of the sustainability definitions in Jordan. Further research to assess the applicability of MCA and AHP tools in the surrounding region of Jordan could help the international donors and NGOs who are actively working in the wastewater sector in the region.

Further research will assess and evaluate using MCA and AHP to evaluate among the treatment options, rather than the indicators.

8. Conclusions

There is a great demand to serve the underserved community in Jordan with a sustainable sanitation solution. Parallel to that, there is also a great demand for an integrated sustainability assessment tool in the Jordanian water and wastewater sector, in order to support the decision makers in comparing, assessing, and selecting the best sustainable options. This study has used the MCA tool to compare and select wastewater treatment options for the case study of Al Azraq town in the eastern part of Jordan. The MCA tool provided a simple and wide approach for stakeholders to rank treatment alternatives by composite scores aggregated and adopted from the sustainability criteria and sub-indicators.

The study found that the AHP approach, combined with the semi-structured interviews with each stakeholder, can be a feasible and a practical approach to developing the weights. The results of composite and aggregated scores can be visualized easily and can be used to select between the alternative options. The study showed that FCW was identified as the best treatment technology for Al Azraq town, compared to the AS and SP.

Stakeholders' engagement should also be included in the early stage of developing the methodology. The use of interviews and thematic analysis can develop a basic understanding of the current method for evaluating and selecting treatment technology; the collected data and information can be used to select the criteria and indicators that lead to having an assessment tool that is compatible with the stakeholder's preference and decision-making context in the water and wastewater sector.

The development and optimization of the MCA tool will also help and support donors and international agencies who are working in the sectors in understanding the local context and selecting the appropriate and sustainable treatment options for each context while minimizing the risk potential.

The development of the MCA tool is basically an iterative process, and it can be reviewed and updated regularly. The criteria hierarchy and weights presented in this research were developed for a unique and specific case in Jordan. However, the methodology can be generalized to perform sustainability assessments for other cases or projects within the water and wastewater sector.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Details of stakeholders, including job profile, organization, and years of experience.

Stakeholders	Job Profile	Organization	Years of Experiences
Stakeholder 1	Wastewater engineer	Ministry of water and irrigation	15
Stakeholder 2	Head of wastewater department	Ministry of water and irrigation	20
Stakeholder 3	Head of operation and maintenance department	Ministry of water and irrigation	18
Stakeholder 4	Consultant in the field of wastewater	University of Jordan	20
Stakeholder 5	Country director	Donor	10
Stakeholder 6	Head or urban development engineering department	Al Azraq municipality	15
Stakeholder 7	Head of designing department	Local wastewater design company	15
Stakeholder 8	Wastewater engineer	INGO	10
Stakeholder 9	Water and environmental engineer	INGO	10
Stakeholder 10	Country director	Donor	10

Table A2. The definition of each indicator used in this assessment, and its type of indication. Positive indication means that higher value of the indicator represents high preference, while negative indication represent the opposite direction of preference.

Criteria	Indicator	Definitions	Type of Value Indication
Technical	Ease of implementation and operation	The ease of implementing and designing the treatment facilities and the ease of operating the process, which is associated with the manpower resources, as well as the levels of skills and training required for operators.	Positive
	Climate change resilience	The ability of technology/process to face different climate change impacts and its ability to adjust or upgrade to adapt to climate change while maintaining treatment efficiency	Positive
	Amount of sludge and by-products (managing the generated sludge)	The required treatment and disposal/reuse process related to the produced sludge and other by-products such as the harvested plants	Negative
Financial	Capital cost	Referee to the total implementation and starting of the treatment process or technology	Negative
	Operation and maintenance cost	Cost related to materials (consumables), staff cost (operators), power consumption, hired and contracted services (e.g., transport, service contract for specific treatment process)	Negative
	Resource/energy recovery and reuse opportunities	The opportunities to recover resources or energy the system can provide, including the treated wastewater	Positive

Table A2. *Cont.*

Criteria	Indicator	Definitions	Type of Value Indication
Environmental	Total emission	Total emission resulted from the treatment process and the WWTP daily operation (direct and indirect emission)	Negative
	Soil and land contamination	The potential contamination of soil and land resulting from the construction and the daily operation process	Negative
	Biodiversity restoration	The ability of the technology to restore biodiversity, flora and fauna	Positive
	Carbon sequestration	The ability of the technology to capture and store atmospheric carbon dioxide in carbon pools such as soil and plant tissues	Positive
Social	Public acceptance	People accepting of having this technology in their town (considering their perspectives regarding odor, land costs, etc.)	Positive
	Provision of aesthetic and green places	The ability of the system to provide green areas and aesthetical places where people can enjoy and visit the treatment plant and its boundaries	Positive
	Willingness to pay	People's willingness to pay tariffs or taxes to have the treatment plant, and to enjoy the main benefits and the co-benefits of the technology	Positive
Institutional	Local personnel capabilities and local technical capabilities	How the technology is familiar with the local technical capabilities, skills, and experiences	Positive
	Compatibility with national strategies, standards, and common practices	The ability of the technology to meet the national strategies, operation and disposal standards, and reuse/disposal practices	Positive
	Organizational effort and financial management required	The required efforts and funds that are requested from the responsible institute to operate to and maintain the technology	Negative

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