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Research Article

Developing an approach for the sustainability assessment of groundwater remediation technologies based on multi criteria decision making

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ABSTRACT

Groundwater is regarded as an important supply of drinking water, as well as for agricultural and industrial purposes. Groundwater pollution worsens as a result of several contaminants such as industrial, urban, and agricultural activities, and the difficulty is to select appropriate groundwater remediation methods. This research develops a technique for assessing the sustainability of groundwater remediation methods by integrating the Multi-Criteria Decision Making (MCDM) method with a Fuzzy Inference Engine. A standard approach for assessing the sustainability of groundwater remediation systems has been developed, consisting of four major criteria: economic, technical, environmental, and social. Following the calculations and determining the priority of all the criteria and techniques based on the weights, the results show the sequence of technologies in which Pump and Treat is the best with 7.83, followed by air stripping with 7.04, and monitored natural attenuation and permeable reactive barrier were the last with 3.70 and 3.19, respectively. The criteria that give P&T the most weight is both the technical and social criterion, with a weight of 8.18, while the criterion with the lowest weight was the economic criterion, with a weight of 4.22. The technical, environmental, and social aspects of P&T were all high, making it the optimum technology where the decision-maker or stakeholder can deal with the decline in the economic component, which is also proof of P&T's preferability and the most sustainable one, and It was also feasible to examine all options to determine which factors are reducing their sustainability and which should be addressed in order to enhance sustainability.

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INTRODUCTION

Groundwater is the essential component and form of the world's freshwater resources (about two-thirds); it is the second biggest freshwater resource after polar ice caps. Groundwater is created by Karst formations from the dissolution of soluble rocks such as limestone, dolomite, and gypsum and is found in pore spaces in the ground [1].

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Groundwater is more valuable than surface water since it is utilized for solely practical needs such as drinking and is rarely used in situ for non-consumptive goals; however, it is now used for irrigation in some areas. Groundwater bodies differ from surface water bodies, as evidenced by the fact that they are used differently [2]. Unfortunately, groundwater resources are polluted or contaminated because of anthropogenic activities [1]. A deterioration of the physical, chemical and biological characteristics decreases the water quality [3]. Groundwater pollution occurs due to the high amount of contaminant brought to the groundwater through filtration, sorption, chemical processes, microbiological decomposition, or dilution. Groundwater pollution can affect or could be affected by many factors including environmental deterioration [4], global warming [5, 6], depletion of the ozone layer [6], impacts on the health of living organisms [3] and reduced efficiency or infertility of farmlands and crop fields [7]. Pollution of groundwater can lead to health concerns, degradation of the ecology, and shortages of water. Health issues may include minor conditions such as nausea, vomiting, irritation of the eyes and nose, diarrhea, or chronic conditions, such as cancer, hepatitis, kidney damage, anemia, nervous system problems, circulation problems, bone conditions, hair loss, and problems with reproduction. It might lead to serious illness, and in rare circumstances, it could lead to death. Water scarcity can happen due to high dependence of the people on groundwater in their daily life [3].

Treatment aims to preserve the health, environment, and agricultural lands of humans and remove hazardous products, components, or pollutants which affect soil and groundwater or reduce the risk of pollutants [8] and make groundwater clean and appropriate for use in humanity and agriculture [9]. Also, It can be used in aquifers to increase the water level. In addition to reducing water pollution levels and diluting water composition. So, groundwater may be used to preserve resources in the groundwater [10].

Many pollutants affect the soil and the groundwater with harmful impacts such as different industrial wastes and processes [9, 11], pesticides and organic and non-organic pollutants [12], mineral oil and heavy metals [8] such as Arsenic [13], grey water footprint (GWF) which contain Nitrate, and Arsenic [10].

Groundwater must be cleansed before it can be used as a water resource, and the purification process is known as remediation. Technical concepts for remediation can be divided into physical, chemical, biological, stabilization, and thermal treatment procedures; depending on the site, these remediation methods might be in-situ or ex-situ. Containment, pump-and-treat, extraction, stabilization/solidification, soil washing, air stripping, precipitation, vitrification, thermal desorption, and bioremediation are the most widely employed methods [14]. These technologies each have their performance and preferences in a variety of areas; thus, stakeholders or decision-makers must assess and pick the appropriate technology to fulfill their goals. This option is hard to make owing to the challenges of remediation, such as significant expenses [3], presence of the chemical compounds, which makes it a challenge to remove them from the surrounding soil and the groundwater itself [15]. Furthermore, unlike surface or air pollution, the primary difficulty is that it is below ground and undetectable; decades might pass before it is ever recognized. Because it is subterranean and three-dimensional, quantifying and mapping is difficult. As a result, several costly cores may need to be drilled to determine their location, and even then, some educated guesswork is required. Furthermore, groundwater does not stay in one location for long, allowing pollutants to enter drinking water aquifers and necessitating costly purifying operations [16]. After identifying the source of the groundwater contamination, the requirement for remediation remains an impediment to selecting the appropriate technology to provide the greatest treatment. In terms of sustainability, there are numerous uncertainties connected with the choice of groundwater remediation techniques. Regulatory, political, and legal concerns can all be stumbling blocks. If the party responsible for the pollution is not readily identified or is no longer in business, responsibility may be determined in court prior to the commencement of the cleanup procedure. When remediation work does begin, ground conditions and the components inside the earth may have changed from when the initial assessment was made [1]. The nature of the technology is almost all under the barriers of technological change and innovation in general, so spending a long time to choose the best technology can be harmful, not beneficial because every day a new update could occur, and more impact is happening [15]. Diseases are widespread among many populations or the impact of plants and animals from the pollution [2, 3]. Factory owners and facilities close to groundwater sites do not agree to stop work until the problem is solved and are not excluded from being a party to pollution until this is proven [17].

Sustainability assessment can be used to pick the right technology in groundwater remediation among many choices; to achieve the target or the goal of the stakeholders or the decision-makers. Sustainability assessment examines the performances of different alternative technologies based on their economic, technical, social, and environmental [11], [18]. Political aspects are also included in sustainability assessment in some studies [11]. These aspects include several criteria that should integrate into the groundwater remediation technologies' sustainability assessment [11, 18].

Multi-Criteria Decision Analysis (MCDA) is a method for making the decision process in a structured and well-organized way, thus providing decision support when there is a large amount of detailed information. MCDM is widely used in management and decision-making, particularly in environmental and energy problems [11, 18, 19]. MCDM has many methods that are used in the determination and weighting the best alternative and the most useful criterion, such as Hierarchy Process (AHP), PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation), TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution), and Analytic Network Process (ANP) and fuzzy-AHP. AHP is the most frequently used method in many environmental studies [11, 18].

There are previous studies in the literature, including the evaluation of groundwater remediation technologies. There is an integration between formulation and computation methods in the earlier studies; however, their computation efficiency is still open to improvement because of uncertainties in many techniques used in groundwater remediation. Other alternatives should be added, like genetic algorithm methods as mentioned in [1]. In [3], dealing with multiple uncertainties in real-world cases was shown, scores were evaluated based on economy and technology with four-time periods only using AHP. Some studies focused on specific pollutants for selection remediation technologies like [13] that focused solely on removing the arsenic compounds from the groundwater or criteria for selecting technologies were very limited [19]. Another practice for sustainable remediation for contaminated groundwater is based on Decision Making Trial and Evaluation Laboratory (DEMATEL) and Analytic Network Process (ANP). Although these methods were beneficial, it is limited to execute for remediation measurement. Therefore, it is needed to propose an approach that can tolerate the uncertainties related to the implementation of remediation technologies, count all sustainability aspects including technical, economic, social, and environmental, and be used for all types of groundwater remediation projects independently from pollutant or location.

In this study, the main goal is to develop a novel framework for the sustainability assessment of groundwater remediation technologies by using AHP through the combination of Fuzzy Inference Engines (FAHP). Because searching for the most sustainable technology for groundwater remediation demands multiple decision criteria that may contain environmental, technical, economic, and social aspects. A fuzzy inference engine can provide tolerance for the uncertainties related to the implementation of remediation technologies since the expert opinions can be quantified. Our approach aims to support decision-makers in selecting the most appropriate groundwater technology for their cases based on sustainability since this approach can serve for any kind of groundwater pollution in any place. Sustainability assessment for groundwater remediation technology has four main criteria: Economic criterion, which means all economical and cost belongings. The technical criterion used generally with the field relates to technology. The environmental criterion means a most of most negative impact on the environment. The social criterion studies the maximization of the social welfare of people. Every criterion has its sub-criterion, and all will be explained in detail [11, 18–20].

MATERIALS AND METHODS

Proposed Sustainability Assessment Approach for Groundwater Remediation Technologies

An approach for the sustainability assessment of groundwater technologies using AHP and a fuzzy inference engine was proposed in this study. AHP includes a set of criteria, and the evaluation of these criteria relies heavily on previous reviews and/or the opinions of experts and surveys. If the decision-maker is in a state of ambiguity and, then fuzzy logic is the ideal technique in this case. AHP method is not very efficient when a user preference cannot define intelligibly since it cannot reflect vague human thoughts. Therefore, using the fuzzy inference engine instead of an averaging technique provides expert opinions for quantification. Fuzzy numbers can include the scoring step of AHP methodology, and the fuzzy inference engine can be adapted to the last calculation step of AHP. This combined version of AHP can be called FAHP. AHP establishes the hierarchy, and the fuzzy set concept makes the scoring and comparison process resilient and eligible to expound experts' preferences. The score of each criterion and the comparison values are given by three numerical values, triangle fuzzy sets [22]. And final quantification is made using fuzzy inference engine rules.

Developing the Hierarchy For AHP

The first procedure is building a hierarchy for the decision. The AHP problem hierarchy contains a goal (decision to be made), various alternatives for getting that goal, and insignificant criteria on which the other options can be judged that connect to the purpose. The first level of the hierarchy is the target; in our case, the goal was to assess groundwater remediation technologies' sustainability. The second level in the hierarchy is setting the main criteria: sustainability assessment criteria, Economic, Technical, Environmental, and Social. The third level is to determine sub-criteria. Considering those requirements, a combined simplified decision hierarchy to pick out an appropriate technology for the groundwater remediation process, [22] as shown in Figure 1. Fourth level is the alternatives which are selected among the most commonly applied groundwater remediation technologies [11, 19, 23] to demonstrate the application of the proposed approach consists of; Pump-treat (P&T), Monitored natural attenuation (MNA), Permeable reactive barriers (PRB), and Air sparging (AS). Users of this approach are free to select their alternatives for their cases.

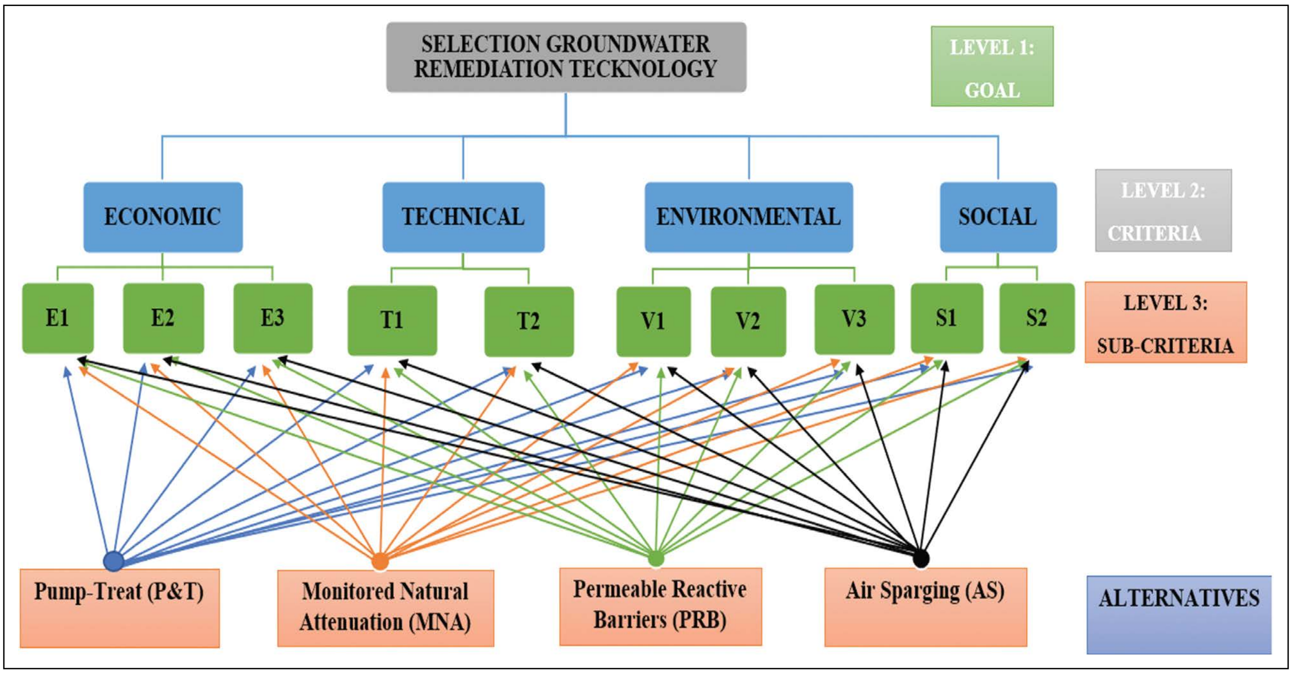

Figure 1. Proposed hierarchy for the sustainability assessment of groundwater remediation technologies.

Table 1. Criteria and sub-criteria for sustainability assessment for groundwater remediation technologies

Criteria	Sub-criteria	Abbreviation	Reference
Economical	1. Capital Cost.	E1	[8], [9], [11], [19], [21]
	2. Operation and Maintenance Cost.	E2	[11], [19], [21]
	3. Detection and Analysis Cost.	E3	[11], [19], [23]
Technical	1. Effectiveness.	T1	[11], [19], [25]
	2. Time for Remediation.	T2	[11], [19], [23]
Environmental	1. Effect of Pollution.	V1	[9], [11], [23]
	2. Production of CO_2.	V2	[12], [26], [27],
	3. Land Use.	V3	[9], [25], [28]
Social	1. Public Health.	S1	[8], [9], [11], [19]
	2. Public Acceptance.	S2	[8], [9], [19], [25]

Environmental sustainability is accountable interaction with the environment to evade depletion or regression of nature resources (in our case is groundwater) and permit for long-term environmental quality. Many criteria influence the sustainability of remediation technology. In this study, groundwater remediation technologies' sustainability was evaluated using four sets of criteria classified as economic, technical, environmental, and social. Used current knowledge and previous data in the remediation of groundwater from contaminations to determine the criteria. Split economic criteria into the next three sub-criteria were made: Capital cost, Operation and Maintenance cost, and Detection and Analysis Cost. Technical criteria were divided into effectiveness and time for remediation. Effect of pollution, Production of CO_2, and Land use were taken as sub environmental criteria. Finally, public health and Public acceptance were evaluated as sub-social criteria. All these criteria are illustrated in Table 1. These criteria are composed in the context of this study and their necessity is explained with the scientific references below. Users of this proposed approach are free to disclude any criteria that are not relevant to their cases or to include any criteria that are needed for their cases.

Table 2. Sustainability variables and their membership functions (economical, technical, environmental, social)

Aspect	Definition	Fuzzy scale
Very Low	This criterion has no effect on sustainability	(0,0,2.5)
Low	This criterion has a small effect of sustainability	(0,2.5,5)
Medium	This criterion has a medium effect on sustainability	(2.5,5,7.5)
High	This criterion has a high effect + on sustainability	(5,7.5,10)
Very High	This criterion has an extreme effect on sustainability	(7.5,10,10)

Economic Criterion

Capital Cost: The capital cost indicates the establishment of plants and facilities for groundwater remediation [8, 9, 11, 18, 20].

Operation and Maintenance Cost: The operation and maintenance costs are linked to the outlays of operation and maintenance of the plants and facilities for groundwater remediation [11, 18, 20].

Detection and Analysis Cost: The detection and analysis costs contain all the outlays for analysis and detection when utilizing the technologies for groundwater remediation [11, 18, 22].

Technical Criterion

Effectiveness: It means the effectiveness of remediation for waste removal from groundwater [11, 18, 23].

Time for remediation: The time for remediation represents the needed time for groundwater remediation [11, 18, 22].

Environmental Criterion

Effect of pollution: It measures the integrated environmental impacts when applying the technologies for groundwater remediation [9, 11, 22].

Production of CO_2: This criterion refers to the total amount of CO_2 emissions that should be avoided if the groundwater remediation or the mechanisms leads to it [12, 25, 26].

Land use: This criterion is used to analyze the land that will be used for the groundwater remediation process [9, 26, 27].

We have to mention that, In recent years, global warming has become an environmental challenge as a result of greenhouse gas emissions (GHEs), and both are severe issues. GHEs are released from carbon dioxide (CO_2), methane (CH4), and nitrous oxide (N2O) [28–31], as well as water vapor, ozone, chlorofluorocarbons, and sulfur hexafluoride [28], all of which are generated by wastewater treatment plants (WWTPs) [28, 29].

There are two types of WWTPs sources. On-site or direct source emissions from fossil fuel burning, methane emissions, and process emissions of other greenhouse gases [28], collection system emissions [29], emissions related to the biochemical treatment process, and microbiological activity in wastewater [31] are among them.

Off-site or indirect sources are emissions from electricity use in the plant [28, 30, 31], heat, air consumption, transportation, chemical use, and sludge stabilization and disposal and reuse processes [29, 31].

CO_2 was the most significant greenhouse gas released as a result of the biodegradation of organic and inorganic compounds [28, 31].

As a solution to this hazardous problem of reducing GHG emissions from various industrial facilities, we may minimize energy consumption, which will also improve the economics [28] and process equipment (with the majority focused on biological processes including activated sludge, stabilization ponds, and aerobic reactors) [31], biogas recovery decreased greenhouse gas emissions as well [29].

Social Criterion

Public health: It measures the effect on the residents' health when applying the technologies for groundwater remediation [8, 9, 11, 18].

Public acceptance: This including the acceptance of the technologies for the groundwater remediation process [9, 18, 24], also it is the acceptance of the land that will use [8], furthermore it indicates that citizens accept all the effects of starting a project such as noise, turbulence, road blocking, and odors if there is [24].

Create the Scale

Sub-criteria in the hierarchy were scored to assign the degree of its importance for the groundwater remediation process's sustainability. The scale for the scoring in this study is given in Table 2. To deal with the suspicion of information in real problems, the fuzzy sets theory was progressed by [32]. It is natural that the scores "excellent" and "very good" may have some snarl in concepts. If it is the case, the overlap can be described using fuzzy sets in the grade definitions. Membership functions are used for the quantifications of fuzzy set grades. The other scoring step in the FAHP method is performing the priority evaluation of criteria using pairwise comparison. The triangular fuzzy number was defined with three parameters as (l, m, u) where, respectively, "l" denotes the smallest possible val-

Table 3. The pairwise comparisons scale of criteria with related to goal with fuzzy numbers [34]

Judgement value	AHP scale	Fuzzy scale
Equally preferred	1	(1,1,1)
Moderately preferred	3	(2,3,4)
Strongly preferred	5	(4,5,6)
Very strongly preferred	7	(6,7,8)
Extremely preferred	9	(9,9,9)
Intermediate values	2,4,6,8	(1,2,3), (3,4,5), (5,6,7), (7,9,9)

ue, "m" indicates the most promising value, and "u" denotes the most considerable potential value to describe a fuzzy event. To determine the relative importance for two criteria in fuzzy AHP-matrix, Triangle Fuzzy Scale was used [33], as shown in Table 3.

Identification of Alternatives

Groundwater pollution is one of the most significant risks because the danger is not limited to the environment only. Still, it is considered a substantial threat to a large class of people who relies on this groundwater as a source of life. The contaminant that leads to groundwater pollution is sourced from different cases, including from factories or a problem with oil pipelines, and many others. In this study, the goal remains to assess the most sustainable remediation technology to refine groundwater and make it suitable for its beneficial use. Four alternatives have been found that can all perform the process of technology and treatment. Still, the choice remains among them linked to certain criteria, and these criteria are economic, technical, environmental, and social, which include several sub-criteria as well.

The method used is FAHP, which they use to set the proportional of the alternatives with consideration to each criterion for sustainability assessment and for calculating the weight coefficients of the criteria in the final hierarchy and ranking the sustainability gradation of the alternative technologies for ground-water remediation.

The alternative technologies are selected among the most commonly used ones in the literature to demonstrate the application of the approach. The users of this approach can determine their alternatives for their cases.

(1) Pump-treat (P&T): This method is the most used, this technology contains pumping out contaminated groundwater with the utilize of a submersible or vacuum pump, and it can make the removed groundwater be purified on the surface of the ground.

(2) Monitored natural attenuation (MNA): This technology is a technique utilizing to observe or examine the progress of natural processes that can decay contaminants in groundwater, consisting of biological degradation, volatilization, dispersion, dilution, radioactive decay, etc.

(3) Permeable reactive barriers (PRB): The emplacement of a permeable barrier performs this technology include reactive materials across the flow path of the contaminated groundwater to intercept and treat the contaminants as the plume flows through it under the influence of the natural hydraulic gradient.

(4) Air sparging (AS): This method encompasses air injection under pressure into saturated zone soils. The injected air dislodges water and creates air-filled porosity in the saturated soils, volatilizes and takes dissolved and adsorbed phase Volatile Organic Compounds (VOCs), and transfers oxygen into the groundwater [11, 18].

Scoring Step

After explaining the sustainability criteria and giving the scoring scales for applying the proposed fuzzy-AHP approach for selecting the most suitable groundwater remediation technology, the first step is to evaluate each alternative according to each criterion in Figure 1. Using Fuzzy-AHP is considered among the best ways to handle complex structures such as sustainability assessment, a complex multi-criteria problem. It is affected by multiple factors and needs more analysis to reach, define and assess factors in a systematic manner. Decision-maker asks the question that could determine the criteria for measuring the sustainability performance of the groundwater remediation technologies. In this study, Fuzzy AHP has been used to determine the best sustainable alternative for groundwater remediation. After developing the hierarchy and scale for scoring, each criterion in the hierarchy is scored based on their contribution to sustainability. It is worth pointing out that the users are allowed to add more or delete some criteria for the sustainability assessment of groundwater remediation technologies according to their actual conditions and stakeholders' preferences [11, 18]. Scoring can be made by literature review or/and expert opinion, which can be asked by the questionnaire, E-mail, or meetings. Here, in the absence of data, the evaluation was made by the author's opinion based on the (if-then) rule. The numbers or the score was taken with fuzzy numbers, as a quantitative domain of linguistic expression which is transferred unified trapezoidal fuzzy number (STFN) shown in Table 4. These

Table 4. Scores that are given for each alternative in fuzzy numbers transferred standardized trapezoidal fuzzy number (STFN)

	Criteria	(P&T)		(MNA)		(PRB)		(AS)	
ECO	CAPITAL COST (E1)	2	4	7	9	5	7	4	6
	O&M COST (E2)	3	5	7	9	6	8	4	6
	D&A COST (E3)	6	8	7	9	7	9	8	10
TEC	EFFECTIVNESS (T1)	8	10	2	4	4	6	7	9
	TIME F REM (T2)	2	4	1	3	7	9	4	6
ENV	EFF OF POL (V1)	6	8	7	9	4	6	2	4
	CO2 PRO (V2)	5	7	7	9	6	8	5	7
	LAND USE (V3)	2	4	5	7	4	6	3	5
SOC	PUP HEAL (S1)	7	9	4	6	4	6	3	5
	PUP ACC (S2)	8	10	1	3	5	7	5	7

trapezoidal membership functions can be shown as A= (a^l, a^m, a^n, a^u), then numbers will be converted into STFN as a^m=a^n, a numerical range correlate to al=am and an=au. If we assume the STFN values were expressed by a^{ij}=(a^l_{ij}, a^m_{ij}, a^n_{ij}, a^u_{ij}), then to find a_{ij} values, we have to find them using the following Equation 1:

$$a_{ij} = \frac{a^1_{ij}+2*\left(a^m_{ij}+a^n_{ij}\right)+a^u_{ij}}{8} \qquad (1)$$

Economical Criterion

The main question is, what is the degree of sustainability of the alternative in terms of economic criteria? If the technologies' costs concerning these criteria are small, the technologies will be less sustainable in terms of economic criteria. Scoring of the alternatives was made using linguistic variables in Table 2, and the literature review given in Table 1 was considered for scoring. They were assigned from "Very Low" to "Very high" considering sustainability principles' costs. Economic criterion contains Capital Cost, Operation and Maintenance Cost, and Detection and Analysis cost. The scoring was made based on the references and author's opinion as shown in Table 4 [11, 18]. for cost in general, P&T has the highest cost because it has the lowest scores, we can see that in the capital cost, which is the highest among the other alternatives, according to that the preferability will be low, so, that mean the high price leads to low sustainability. Operation and maintenance cost is also the highest due to the number of occupational and facilities. The number of wells that make all these facilities need more price, the same is here, the increase in operation and maintenance cost means to decrease the sustainability. As we mentioned, the number of facilities and the large used spaces needs efforts and money to prepare, detect and analyze them, so detection and analysis cost. However, it is not the highest, still has an effect on sustainability and decrease the preferability as well. So, P&T has the most increased cost, but to take the final decision, all factors will be studied, not only the cost. AS is the second-highest cost, then PRB, and the lowest cost is MNA.

Technical Criterion

The technical aspects also significantly impact sustainability, not only on groundwater remediation, but it considers a sufficient criterion in most sustainability systems. So, the sustainability will be high if the quality of the alternatives' technological aspects is high because it is a benefit type. The technical criterion includes the effectiveness of the remediation process for contaminated groundwater and soil surrounding it and the duration of groundwater's remediation process. Linguistic variables in Table 2 were used. The scoring was made considering the literature's knowledge and author's opinion [11, 18, 34].

Starting with efficiency, which means the quality of removal of pollutants, P&T is the most efficient alternative; this efficiency leads to high sustainability and high preferability, so it has the highest scores. Looking at the time of remediation, the time in P&T is mostly long, it takes years, and this time will affect sustainability, which leads sustainability to decrease. So, the time of remediation is the longest, and it takes the lowest scores. AS, PRB and MNA arranged gradually from highest to lowest, as shown in Table 4.

Environmental Criterion

The environment is the groundwater source, so preserving from any contaminations or pollution is the main goal. if its sub-criterions' values are low, that means the sustainability will be low, as shown in Table 3.

Environmental criterion consists of Effect of pollution, Production of CO_2, and land use. They measure the integrated environmental impacts when applying the technologies for groundwater remediation and the maximum possible area that will be used. The soring was made by considering the knowledge in the literature shown in Table 1.

When we look at the environmental factors in P&T, AS, and PRB, the scores are almost low, or medium, which means their sustainability is somewhat low; even if the difference is so slight, it is still low. Except for MNA because it is a monitoring method more than a remediation method.

Table 5. Pairwise comparison of sub-factors factors and their converted numbers in STFN

	E1				E2				E3			
E1	1	1	1	1	1	1	3	3	2	2	4	4
E2	1	1	0.33	0.33	1	1	1	1	1	1	1	1
E3	0.5	0.5	0.25	0.25	1	1	1	1	1	1	1	1
	T1				**T2**							
T1	1	1	1	1	6	6	8	8				
T2	0.1666	0.1666	0.125	0.125	1	1	1	1				
	V1				**V2**				**V3**			
V1	1	1	1	1	2	2	4	4	5	5	7	7
V2	0.5	0.5	0.25	0.25	1	1	1	1	4	4	6	6
V3	0.2	0.2	0.142	0.142	0.25	0.25	0.166	0.166	1	1	1	1
	S1				**S2**							
S1	1	1	1	1	4	4	6	6				
S2	0.25	0.25	0.1666	0.1666	1	1	1	1				

The Effect of pollution on P&T and its environmental impact is medium, which could mean medium preferability and sustainability. Also, the Production of CO_2 is medium, also AS, but comparing with PRB, so its sustainability is better than PRB. The land used for both AS and P&T is low sustainable due to low scores and big used lands. So, in environmental factors, the results are almost close except MNA.

Social Criterion

Social aspects are considered significant in terms of sustainability, as they are the first and last beneficiaries of resources. A class of society uses these resources as the primary source of their lives; therefore, it is essential to follow these sources and their validity. If the value of public health is high and the people's acceptance, that means sustainability will be better. So, the measure of social aspect is based on investigating the effect on public health, which measures residents' health when applying the technologies for groundwater remediation.

Linguistic variables in Table 2 were used, and scoring was made by using the literature knowledge given in Table 1. Public health and public acceptance have somehow high scores, which means the acceptance of people was high. The effects of P&T on their health were low or medium, which means when the people's acceptance is high, sustainability is high, and when public health is not affected too much or not be affected, that also means the sustainability is high, as shown in Table 4.

Compare Factors Pairwise and Conversion to STFN

Each sub-criterion is compared to the other sub-criteria under the same group's main criterion based on its relative contribution to the sustainability assessment. Chang's 1-9 scales are used for double comparison [33]. Significance ranges from the number 1, which is equal in importance, to the number 9, representing the most important. If there are slight differences between the factors, scales (2, 4, 6, and 8) are used (Saaty, 2001), as shown in Table 3. Experts can give their scores on a fuzzy scale if necessary, but the pairwise comparison was based on previous data. The next step is to convert scores to STFN. Since the scores for measuring a factor index and even pairings are in different forms, it is necessary to convert them into a familiar model before performing the calculations. STFN and conversion equation is preferred for this study. The trapezoidal organic function can be transformed in the form A= (a^l, a^m, a^n, a^u). In triangular fuzzy numbers are converted into STFN as a^m=a^n, a numerical range coincides with a^l=a^m and a^n=a^u, in Table 5 all this data was shown [11, 18, 35, 36].

Calculate Priority Weights

To calculate priority weights (w_i) of criteria in comparison matrix Table 6, Arithmetic

the averaging method is given in Equation 2:

$$w_i = \frac{i}{n_j}\sum_{j=1}^{n}\frac{a_{ij}}{\sum_{k=1}^{n}a_{kj}} \quad i, j = 1,2, \ldots, n \tag{2}$$

Which aij is the defuzzied form of a score that is given for the comparison of F_i and F_j agent in the same level in which there are n agents. If total STFN is shown as aij=(a^l_{ij}, a^m_{ij}, a^n_{ij}, a^u_{ij}), the crisp value of a_{ij} can be calculated by using defuzzification Equation 1 above.

W'_i or the weight of factor index in the hierarchy. W(i) section points to the priority weight of i section above.

Factor index in the case of being t level above it which is given in Equation 3:

$$w'_i = w_i * \prod_{i=1}^{t} w^{(i)}\,\text{section} \tag{3}$$

Table 6. Priority weights of sub-factors which are calculated by using Equation 1, 2, 3

	E1	E2	E3	W
CAPITAL COST (E1)	1	1.2	1.8	**0.48802**
O&M COST (E2)	0.4	1	1	**0.27394**
D&A COST (E3)	0.225	1	1	**0.23804**
TOTAL	**1.625**	**3.2**	**3.8**	**1**
				W
EFFECTIVNESS (T1)		1	4.2	**0.86362**
TIME F REM (T2)		0.0875	1	**0.13638**
TOTAL		**1.0875**	**5.2**	**1**
				W
EFF OF POL (V1)	1	1.8	3.6	**0.61405**
CO2 PRO (V2)	0.225	1	3	**0.30202**
LAND USE (V3)	0.10286	0.125	1	**0.08392**
TOTAL	**1.32786**	**2.925**	**7.6**	**1**
				W
PUP HEAL (S1)		1	3	**0.81944**
PUP ACC (S2)		0.125	1	**0.18056**

The priority weights of the Factor index of factors in the comparison matrix were shown in Table 6.

In economic factors, high importance or preferability was given for the capital cost. If the capital cost is high, that means this project is hard to start from the beginning. The lowest is detection and analysis because it is possible to find multiple ways to detect or analyze. Still, it is not easy to provide capital and operational and maintenance costs; it is the project's foundation. In technical factors, efficiency is the most important factor more than the time of remediation. The efficiency determines if this project is useful to solve the problem or not, or how much good is it, through making the desired result. In environmental factors, the aim is to keep the environment clean as possible. So, the impact of pollution and production of CO_2 have more importance than the land used. However, we consider it an effective factor because if the land is bigger the possibility of pollution is high. There is no doubt about the importance of public health in social factors than public acceptance because this project aims to maintain the public's health by remediating the contaminant water.

So, after all the calculations, we found that the economic factors have the highest importance. Social is the lower importance. We can consider that the project's adequate financial support gives the community a good impression when providing the correct and appropriate atmosphere for work. The quality of equipment and work maintains the health and safety of them surrounding the project. Calculate The Factor Index (FI):

The factor index can calculate by Equation 4, where P_i is the STFN form of the score that masters give to the bottom level sustainability factors in the hierarchy, n means the number of bottom-level sustainability agents in the hierarchy which belongs to a specific primary sustainability source, as shown in Table 7 [36].

$$FI = \sum_{i=1}^{n} P_i^* * w_i' i = 1,2 \dots \dots \dots, n \quad (4)$$

Convert STFNs to Fuzzy Sets

The next step is Fuzzy inference which converting STFNs to fuzzy sets. It is necessary to transform the economic, technical, environmental, and social scores of P&T and the other alternatives to fuzzy sets. The crossing points between STFN forms of economic, technical, environmental, and social scores and their particular membership functions give the membership degrees of those agents in the corresponding fuzzy set, which is shown in Figure 2 for clarification of scenario execution. In this step, intersection points of economic, technical, environmental, and social scores with fuzzy membership positions were found to fulfill this main factor's classes and membership degrees. In Figure 2, the economic, technical, environmental, and social membership functions were shown. In P&T economic, technical, environmental, and social STFN is between Medium, High, and Very High classes.

In economic which in grey color = (3.22; 3.22; 5.22; 5.22), Then the technical STFN in yellow color = (7.18; 7.18; 9.18; 9.18). For environmental STFN in the red color = (5.36; 5.36; 7.36; 7.36). Finally, for social STFN in the green color = (7.18; 7.18; 9.18; 9.18).

Table 7. Factor Index of the alternative technologies calculated using Equation 4 (PI: Factor value for the criteria and W: priority weight)

PI*W	(P&T)	PI*W	(MNA)	PI*W	(PRB)	PI*W	(AS)
0.976	**1.952**	3.416	4.392	2.440	3.416	1.952	2.928
0.821	**1.369**	1.917	2.465	1.643	2.191	1.095	1.643
1.428	**1.904**	1.666	2.142	1.666	2.142	1.904	2.380
6.908	**8.636**	1.727	3.454	3.454	5.181	6.045	7.772
0.272	**0.545**	0.136	0.409	0.954	1.227	0.545	0.818
3.684	**4.912**	4.298	5.526	2.456	3.684	1.228	2.456
1.510	**2.114**	2.114	2.718	1.812	2.416	1.510	2.114
0.167	**0.335**	0.419	0.587	0.335	0.503	0.251	0.419
5.736	**7.375**	3.277	4.916	3.277	4.916	2.458	4.097
1.444	**1.805**	0.180	0.541	0.902	1.263	0.902	1.263

Table 8. The matrix of fuzzy inference engine for P&T. (Values in the parenthesis are showing the membership degrees for the classes (VL: Very low; L: Low, M: Medium, H: High, VH: Very high, ECO: Economical, TECH: Technological, ENV: Environmental, SOC: Social)

				SOC	
ECO	TECH	ENV	M(0.13)	H(0.67)	VH(0.67)
L(0.29)	**M(0.13)**	**M(0.85)**	M(0.13)	M(0.13)	M(0.13)
M(0.92)	**H(0.67)**	**H(0.05)**	M(0.05)	H(0.05)	H(0.05)
H(0.92)	**VH(0.67)**	**VH(0.05)**	H(0.05)	H(0.05)	H(0.05)
L(0.29)	**M(0.13)**	**M(0.85)**	M(0.13)	M(0.13)	M(0.13)
M(0.92)	**H(0.67)**	**H(0.05)**	M(0.05)	H(0.05)	H(0.05)
H(0.92)	**VH(0.67)**	**VH(0.05)**	H(0.05)	H(0.05)	H(0.05)
L(0.29)	**M(0.13)**	**M(0.85)**	M(0.13)	M(0.13)	M(0.13)
M(0.92)	**H(0.67)**	**H(0.05)**	M(0.05)	H(0.05)	H(0.05)
H(0.92)	**VH(0.67)**	**VH(0.05)**	H(0.05)	H(0.05)	H(0.05)

Therefore, corresponding fuzzy set for:

Econ ={(Low, 0.29), (Medium, 0.92), (High, 0.92)}.

Tech ={(Medium, 0.13), (High, 0.67), (Very High, 0.67)}.

Envi ={(Medium, 0.85), (High, 0.05), (Very High, 0.05)}.

Soc = {(Medium, 0.13), (High, 0.67), (Very High, 0.67)}.

Fuzzy Inference System

The following step is a fuzzy inference which If–then rules are used to achieve Sustainability Magnitude (SM) by combining economic, technical, environmental, and social components. Fuzzy crossing (minimum) operation provides combining economic, technical, environmental, and social composition parameters with "and" laborer, leading to getting amputate fuzzy SM results. Therefore, a fuzzy association (maximum) operation is used for getting a single fuzzy membership function.

Based on the data in Table 8 and Figure 2, according to fuzzy inference steps, and fuzzy rule base that was contagious by using fuzzy classes of agents for all of the combinations of them. As an expert if the economy is low (0.29), technical is medium (0.13), environmental is medium (0.85). social is a medium (0.13), then SM is medium (0.13). Because if most of the factors have a medium performance, the SM accordingly will have a medium class, and the cost-effectiveness is too small or negligible. Another explanation is if the economy is medium (0.92), the technology is high (0.67), the environment is high (0.05), and the social is very high (0.67). SM is high (0.05) because most of the factors are in the high class, and comparing with three essential factors, the cost will follow their class. Still, another decision-maker could decide it to be medium (0.05), and also, it is right.

Economic, technical, environmental, and social criteria were composed using "And" laborer to achieve SM. The membership degree of that medium SM is 0.05, which considers the minimum membership degree among economic, technical, environmental, and social criteria combined. Membership degrees of SM are inferred using a

Table 9. The sustainability sequence of the four technologies

	P&T	MNA	PRB	AS
FINAL WEIGHT	7.83	3.70	3.19	7.04
THE ORDER	**1**	**3**	**4**	**2**

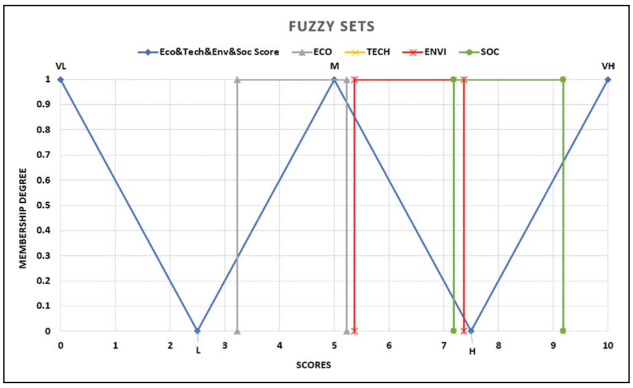

Figure 2. Fuzzy sets of Factor Index for P&T and fuzzy sets for the scales of main criteria [VL: Very low; L: Low, M: Medium, H: High, VH: Very high, ECO: Economical, TECH: Technical, ENVI: Environmental, SOC: Social, (here Soc and Tech have the same values)].

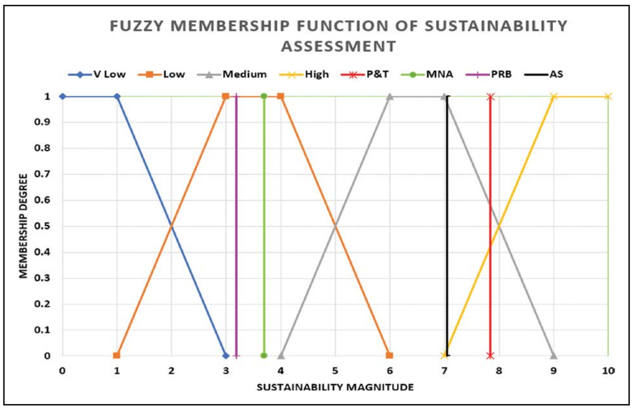

Figure 3. Determination of classes and membership degrees of sustainability magnitude for groundwater remediation techniques.

fuzzy union maximum operator and shown in red color sells in Figure 2. The maximum membership degree for the significant combination in the rule base is 0.13, so a high SM membership degree is 0.13. Membership degrees for other sustainability classes (medium, low, and very low) were obtained analogously.

Defuzzification

This step is based on the previous step in which membership degree for sustainability assessment was obtained, defuzzied calculation has been held in Equation 5:

$$SM = \frac{0*1+0*4+0.13*7+0.05*10}{0+0+0.13+0.05} \quad (5)$$

SM = 7.83

Defuzzified sustainability magnitude 7.83 was drawn on the fuzzy membership function of sustainability assessment to attain actual class and membership degree of sustainability assessment. In Figure 3, SM is in the high group, where the high group starts from 7, meaning that P&T groundwater treatment techniques belong to the high class, also AS belongs to the same class. For the other three alternatives, the same steps and calculations were made, and the results were for sustainability class and membership degrees.

RESULTS AND DISCUSSION

Multi-criteria decision analysis is an efficient methodology to set the most sustainable technology for groundwater remediation because it includes all required realistic conditions due to its systematic and flexible nature and the decision-maker's predilection. Owing to the hierarchical structure of AHP, the necessary criteria are easily organized. When there was replication or lack of required criteria during the development of hierarchy, it was easily noticed, and hierarchy was modified easily to the final version in Figure 1. Ten criteria used in this study for sustainability assessment of groundwater remediation technologies were the economic, technical, environmental, and social conditions for this study. The proposed approach is very flexible for adding new criteria when needed for different cases. According to the results of the demonstration for this approach, final weights given in Table 9, P&T is the best technology, followed by AS, MNA, and PRB.

Take Pump and Treat that all the calculations were made for it. The technical and socials factors have the highest score evaluation with 8.181, 8.180, respectively then the environmental with 6.362, and last the economic factor with 4.226, as shown in Figure 4. Technical and social factors have close scores evaluation to each other. The difference between them is about 0.001, so we can consider the technical as a second factor and social as the first, which changes according to the decision-maker and the circumstances and preferences.

When we look at all the results from all previous working, we found P&T had the preference on working steps, although the presence of some weak points, such as the highest cost, still has the best performance, which the effectiveness is the best in P&T; also the public acceptance and

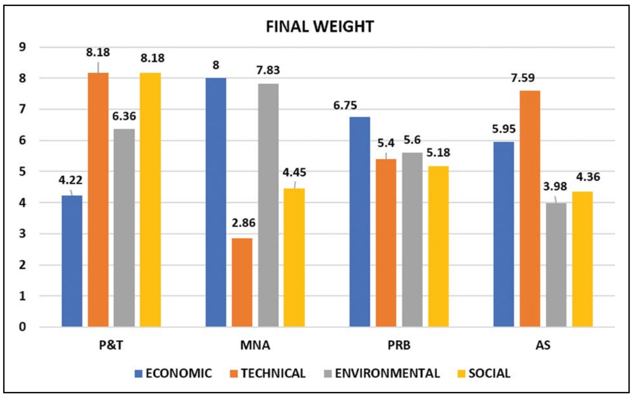

Figure 4. Factors priority.

the public health has good scores, at to that comparing with other technologies the environmental factors also was acceptable after MNA technique, furthermore P&T through working on the matrix of fuzzy sets. Fuzzy inference engine was the only technique that did not have a very low, low among the others, and three of the factors among medium, high, very high classes, which means the literature and the author/ decision-maker have near or the same opinion about using this technology.

Comparing with the other technologies, the depth in P&T and AS is the best which these technologies could go down for long distances, then MNA, PRB is the last. Then for the permeability of the groundwater, it is suitable for P&T comparing with the others. Form the most critical factors are pollution, which considers light for AS and MNA, and the heavy in P&T and PRB, which is hard to remove. The maturity and effectiveness are high for all technologies except PRB are medium or weak. The cost is low or acceptable for all, but too high for P&T. Another comparison item is the land use, which affects the other factor is medium for AS and small for MNA, and very big for the others. The time for remediation is long for P&T, acceptable for AS and PRB, and short for MNA.

So, to analyze every technique separately, starting with As, the advantages are that it is easy to install, has small land uses and requires no storage, removal, treatment, low cost, short treatment time, and minimal disturbances. While the disadvantages are needed to test, lack of information and data, in some cases could be no effective process, and the processes inside could be interacting with each other [37]. The second technique is P&T; the advantages are: decontamination of pumped groundwater could be designed according to the present contaminant, and it is advantageous. While disadvantages include the long average treatment time (from years to decades, especially for highly heterogeneous aquifers, and the contamination caused by poorly soluble compounds); the inability to target the source of contamination, the necessity for treatment to remove contamination from water, the higher energy demand, and the associated costs [38]. The third technique is MNA, and its advantages are lower cost, small land use, low risk, and no waste. Disadvantages are less effective, change groundwater geochemistry, take a long time, and need more control and monitoring performance [37]. The last technique is PRB, and it has many advantages such as This approach is more successful for treating many types of contaminants in groundwater and is considered a sustainable treatment method. It also conserves groundwater resources, is underground, and has little interaction with surface development. PRBs reduce the amount of groundwater and soil that must be treated; moreover, this technology has minimal maintenance and operating expenses, and PRBs' lifetime may be prolonged for decades. This technique also has many disadvantages such as long periods were necessary to manage and monitor the dangers posed by a persistent pollutant source, also underground structures, geological conditions, and site characterization are all frequent constraints to this technology's development, and Reactive media are frequently removed or replaced after a process [39].

As a decision-maker and according to these advantages and disadvantages, we found the most effective method is P&T, add to that fundamental characteristic that allows different designs according to the pollutants. Simultaneously, AS could be less effective, and the data could be not available, so, compared with the disadvantages of P&T, AS is not acceptable to all the decision-makers.

Removing more pollutants and get very clean groundwater is the primary goal of all these processes. Paying on the project and use excellent quality material and good workers make the sustainability high; because using the low budget to solve the problems resulted in making all the projects not suitable. So, economic and technical factors play a sensitive role in increasing effectiveness and getting a good project.

The environmental impacts are no less significant than the technical and economic aspects, as these three factors complement each other. Using the right equipment can protect the environment and people from the risk of pollution. In the effect of the Environmental factors of pollution and CO_2 productions, all that makes this factor has high scores because the protection from any pollutant what makes this factor has high scores and increase the sustainability and makes the decision-makers satisfied.

The social side is also essential because the successful project gets approval from the surrounding society, ensures a good chance for working, benefits from the project, and protects them from the harmful impacts.

To put the criteria in order from Figure 5, the effectiveness has the highest weight, public health, effect of pollution, and capital cost. That supports that the four criteria are no less important than each other even if the weight changed based on another decision-maker; that does not mean any criteria is not essential.

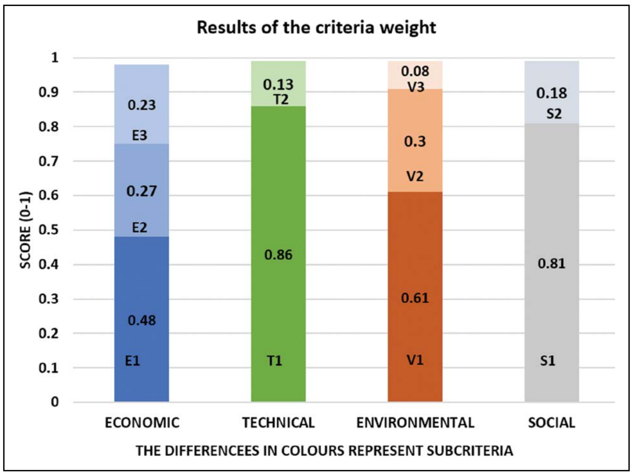

Figure 5. Weights of sub-criteria relative to main criteria.

If we said, these last criteria are in the first stage, according to Figure 5, CO_2 production, and operation and maintenance cost in the second stage in order. In the third stage, detection and analysis cost, and public acceptance which most part is their acceptance of the technologies that will use in groundwater remediation, and guarantee that will not affect the society by any means, as the use of the best equipment and maintenance of devices periodically protect from the occurrence of hazards, pollution, or harmful emissions that threaten the health and safety of society, which in turn can cause lack of approval from the community, So, detection and analysis cost and public acceptance have somehow a medium evaluation because the process of detection and analysis may be simple, available and low-cost, or it may be complex and challenging to complete, depending on the site, the polluter, the nature of the work, and other factors.

As for public acceptance, it is one factor that cannot guarantee it due to the change of public opinion or their division of several opinions. The land used and the time of remediation complements the other criteria; compared to different criteria, it had a somewhat lower evaluation, but at the same time, we cannot consider it as an inevitable factor, and its affection on the project does not make significant which could stop the project. As shown in Figure 5, only land use had deficient weight scores, which could consider as the main cause to make the sustainability in high class, so we have to foe solutions that could increase the low and the medium in the next studies.

In order to accept the public, for example, the public must be aware of the duration of the project, and all matters related to it, in terms of possible inconvenience, noise, smells, and blocking roads, as well as the benefits resulting from the project such as decontamination or increased flow of freshwater to them or the establishment of a project because of this water. This new project may provide them with job opportunities and other things, which increases their acceptance of the project. The cost of data and its analysis may be less because it has been accessed and well known through public help, this can also facilitate and give the decision-maker an initial idea about the technique that can be used in groundwater remediation, and it can facilitate the process of determining the required time for the remediation process.

Results obtained from the demonstration of the proposed approach in this study clearly show the benefits of the proposed approach. Firstly, the results of the proposed approach support decision-makers for listing the alternative remediation technologies for their cases owing to the quantified sustainability scores calculated with a fuzzy inference system. Secondly, decision-making supporters can easily analyze their suggestions in terms of sustainability aspects by using the priority weights and uncertainty tolerance owing to fuzzy scoring. Finally, demonstration of the proposed approach clearly shows the flexibility of the proposed approach for application to any remediation project.

CONCLUSIONS

In this study, an approach for the sustainability assessment of groundwater remediation techniques was proposed, and the benefits of the proposed approach were demonstrated with a case project. Alternatives were evaluated and their sustainability was quantified owing to the combination of AHP and Fuzzy Inference Engine in the proposed approach. Quantification provided the listing of the alternatives according to their sustainability. P&T has the highest sustainability weight with 7.83 over 10 for the case project. The other techniques are AS, then MNA, and in the last PRB with 7.04, 3.7 and 3.19, respectively. Another benefit of the proposed approach, if there are any doubts about the project or in case there are any updates, the decision-maker could easily examine the criteria since their contribution to the decision is quantified as priority weights. Moreover, the proposed approach provides easy communication between stakeholders. Adding another main or sub-criteria may be more helpful in determining the best alternative, as it may be possible to add political criteria that are concerned with regulations and laws or some other criteria that correspond to the status and location of the site, pollutants, conditions, and the decision-makers vision and others.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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