Research Paper:

A Systematic Approach to Using A Fuzzy Inference System and Comparing it With Multi-criteria Decision-Making Techniques for Environmental Management of Crude Oil Contaminated Soils in an Oil Pump Station

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ABSTRACT

Background & Aims of the Study: Oil pollution has a significant impact on soil properties. There are various physical, chemical, biological, or a combination of these methods to deal with it. An important challenge in managing oil-contaminated soils is choosing the ideal method (s) to deal with them. Different methods have been used for decision-making, but can the fuzzy inference engine be used in environmental decisions? The present study investigated the efficiency of a fuzzy inference system for environmental management of crude oil contaminated soils in an oil pump station in southwestern Iran in 2019.

Materials and Methods: Four soil samples were taken to identify the current situation of oil pollution in the study area. Factors, such as the extent of pollution, duration of pollution, climatic, geographical, and biological properties, and the type of soil used in the study area were also determined. Seventeen methods to deal with oil pollution in the soil were identified. Based on the data type, Mamdani fuzzy method was used. For input data, the triangular membership function used the maximum-minimum combination of operators in the inference step, and the Center of Gravity (COG) method was used for defuzzification.

Results: Based on the results of the fuzzy method, land farming with a membership of 0.071 to a completely desirable set, the best method to deal with oil pollution in the soil was determined.

Conclusion: The results of this study and its overlap with other methods of prioritizing options in managerial decisions showed that the fuzzy inference engine could be used as an intelligent system for prioritizing options and decision-making.

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1. Introduction

Can mathematical machines and methods be used in environmental management? In terms of various decision-making criteria, environmental management requires methods to optimize decisions and performances. Most of these decisions are based on the opinions and experiences of experts and specialists, and often a wide range of results is seen in experts' decisions. This range is derived from different intuitive judgments of experts [1]. Some methods have been developed to promote integration in decision-making, including Multi-Attribute Decision Making (MADM) methods [2]. The usual way of making environmental decisions is to classify information and rank decision criteria [3]. Another method used in environmental management is the fuzzy inference system, which is based on the theory of fuzzy sets. Fuzzy logic was first invented in 1960 by Dr. Lotfizadeh, a professor of computer science at the University of California, Berkeley [4]. According to this theory, a fuzzy set on a source set X is a set of pairs (Equation 1):

$$1.\ A=\{\mu_A(x)/x: x \in X,\ \mu_A(x) \in [0,1] \in R\}$$

The function μ_A (x) of the membership grade of the fuzzy member, x , is called set A. The membership grade function can accept real values between 0 and 1 [5]. In fuzzy logic, imprecise reasoning or ordinary logic is a particular case of approximate reasoning. Any logical system can be converted to fuzzy logic. Knowledge is considered a set of fuzzy or flexible constraints on variables. The inference is considered the process of disseminating these constraints, and all problems have a solution that indicates the degree of desirability (possibility) [6]. The present study aimed to achieve an ideal solution to reduce or eliminate oil pollution from the soil. Methods have been proposed for managing soil oil pollutants, which fall into three categories: physical, chemical, and biological [7]. Comprehensive guidelines have been developed in different countries to deal with oil pollution in the soil. For example, the management mechanism of contaminated soils in Japan is as follows:

1. Determining the type of pollution

2. Determining and recording the exact areas of contamination

3. Health risk management

4. Sampling and measuring contaminants

5. Determine the infected areas and areas exposed to pollution on the map

6. Describe the properties of the land

7. Describe the properties of the climate

8. Determine the area of land required for clearing

9. Including the desired method for cleaning in place or another place.

10. Description of items with legal and commercial requirements

11. Determining research companies

12. Determining the best method based on residual pollution, commercial index, and health risk

The mechanism of contaminated soil management in China is also shown in Figure 1.

The main criteria for selecting the ideal method of controlling oil pollution in soil are implementation cost, environmental effects, effects after disposal, use of the soil after disposal, fit to the soil type, and health effects [8]. The use of models and methods based on numbers reduces the possibility of error and increases the validity of the results [9]. The present study investigated the possibility of using fuzzy logic to decide on an ideal option for cleaning crude oil-contaminated soils in an oil pump station. Petroleum products are dangerous and resistant pollutants and contain compounds that accumulate biologically in the food chain [10]. Petroleum pollutants, or products derived from crude oil, include fats, lubricating oils, gasoline, aromatic hydrocarbons, and halogenated petroleum hydrocarbons [11]. These materials also contain a group of heavy metals (Pb, Ni, Hg, Cd, Ba, As, and Se) that have destructive impacts on the environment. These compounds are the main factor in changing soil fertility [12, 13]. On the other hand, with the penetration of petroleum products into the soil, groundwater contamination is possible. The extent of this penetration depends on soil properties (such as porosity and moisture content) and the nature and quantity of contaminants. After the petroleum hydrocarbons enter the soil, they compete with the climate for replacement in the pits [14]. Deciding on the ideal methods for controlling and eliminating soil pollution is a complex process that requires extensive studies of the conditions in the area and knowledge of common methods of pollution control [15]. To choose a

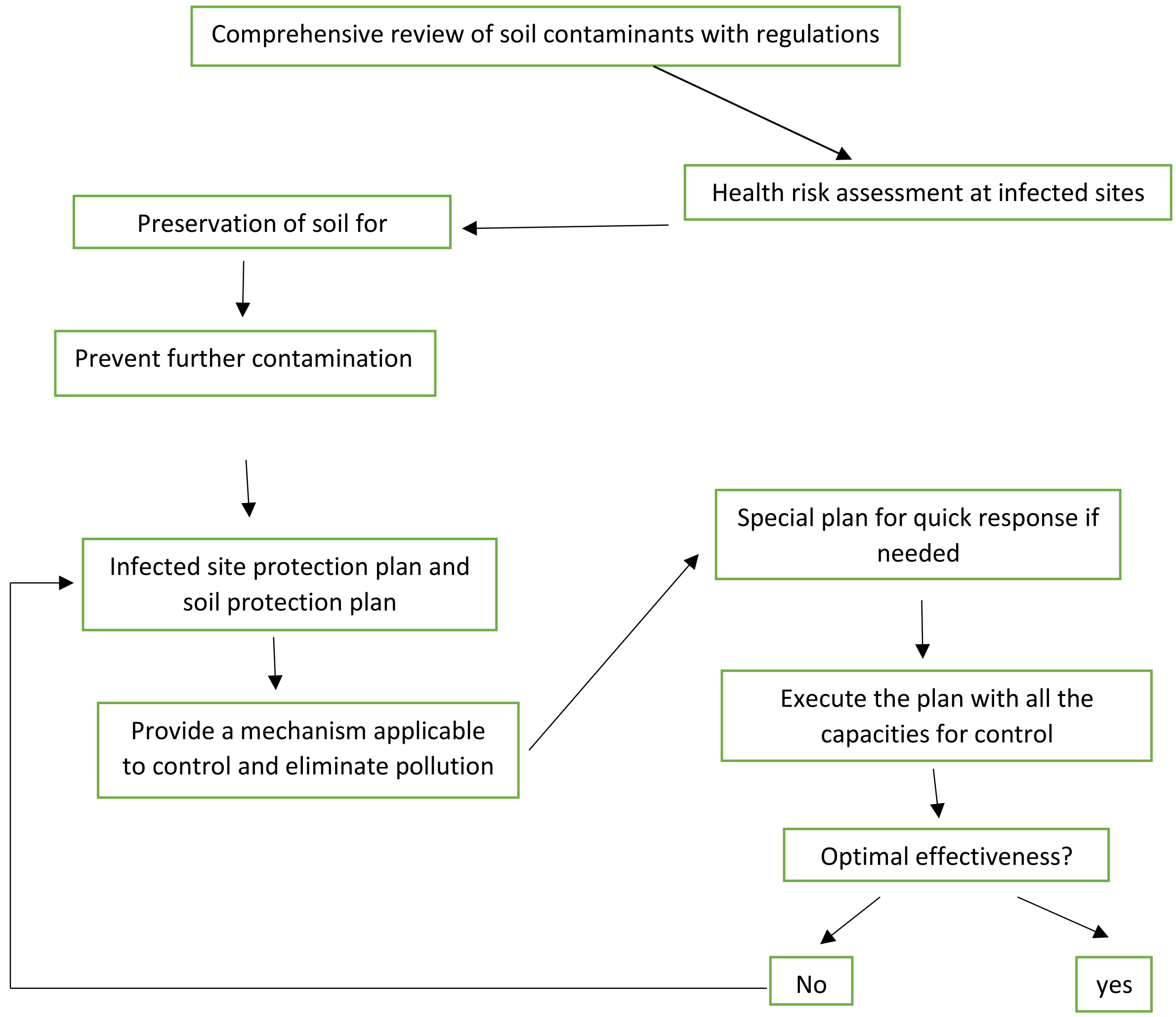

Figure 1. Mechanism of contaminated soil management in China

technique to control or eliminate soil pollution, the following questions must be answered [16, 17]:

- What is the purpose of isolating or controlling soil contamination?

- Due to the biological sensitivities of the area (flora and fauna, the potential for pollution, surface and groundwater, land use, etc.), is it necessary to eliminate pollution? (Need to assess the risk of pollution)

- Have the side effects of the technique been determined?

- Are the necessary costs for the practical implementation of the process determined?

- Has the method's feasibility been studied in non-laboratory conditions, considering factors such as the area and depth of contamination?

- Is there a plan for managing pollutants after removal from the soil?

- Will the former use be possible after removing the contaminant from the soil?

- If it is not possible to access the previous use, can a new use be assigned to the location?

Among the research that has been done in the field of applying mathematical methods in environmental management, we can refer to that conducted by Ameri-Arab et al. as the application of Multi-Layer Perceptron neural network in locating municipal solid waste landfills with emphasis on hydrogeomorphic properties [9] and also the research by Gonzalez et al. entitled "Ecological management of sea hills based on climatic data estimated in artificial intelligence" [16]. This study was done to carefully review the common methods of cleaning soils con-

Figure 2. Position of the studied oil pump station in Iran

taminated with oil derivatives and to express the properties, advantages, and disadvantages of each method based on fuzzy logic to find the best method for cleaning soils contaminated with oil derivatives, based on the criteria set and appropriate to the climatic and geographical conditions of southern Iran.

2. Materials and Methods

In this study, the application of a fuzzy inference system in environmental management decision-making of crude oil contaminated soils in the area of an oil pumping station in southwestern Iran in 2019 was investigated. The study's statistical population was the soils of an oil pumping station in southwestern Iran (Figures 2 and 3). This oil pump station provides the required feed for some of the oil refineries in Iran.

In order to optimally identify the current situation of oil pollution in the study area, seven samples were collected in the area of oil reservoirs using the Peterson-Grab method (dimensions of 10×5×15 cm). The parameter of Total Petroleum Hydrocarbons (TPHs) and soil texture of the region were also determined based on the soil texture triangle. In addition to the mentioned cases, the extent of pollution, the elapsed time of pollution, climatic, geographical, biological properties, and the type of soil used in the study area were also determined. Based on studies conducted by various authorities, such as Mrozik [17] and based on the ability to implement different

Figure 3. Location of the studied oil station pump on Google Map

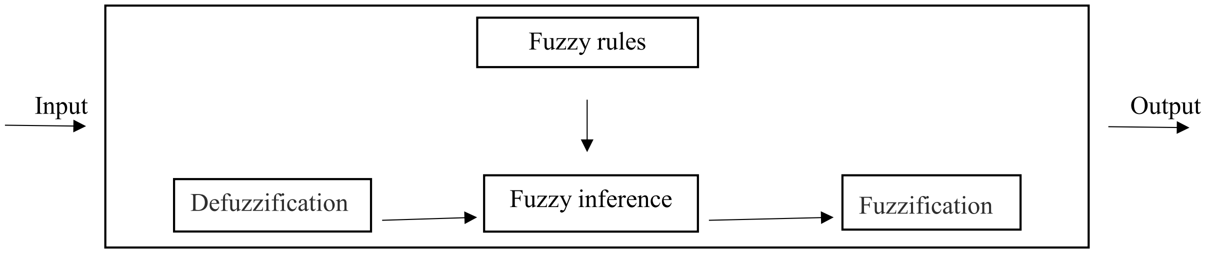

Figure 4 Fuzzy inference system [5]

methods of controlling oil pollution in the soil for the study area in southwestern Iran, methods of bio-extraction, plant stabilization, bio-ventilation, bio-stimulation, plant evaporation, root decomposition, plant decomposition, land-farming, bio-sparing, biomass, chemical oxidation, electro-kinetics, supercritical steam extraction, stabilization, mechanical handling and burial, combustion, heating (evaporation with temperature change) and soil washing were considered [11, 17, 18].

Options were prioritized based on two multi-criteria decision methods (AHP for criteria prioritization and TOPSIS for options prioritization) and a fuzzy inference system.

The AHP method prioritized the criteria based on the pairwise comparison method presented by Saaty [19]. After forming the decision matrix, the criteria are compared in pairs in this method. Then, the elements of each level are compared in pairs with their element at a higher level, and their weight is calculated. By combining relative weights, the final weight of each option was determined. All comparisons in the Analytic Hierarchy Process were performed in pairs. In this comparison, decision-makers will use oral judgments.

The 6-step method proposed by Lai et al. [20] was used to prioritize the options in the TOPSIS method. These steps include: (a) forming the decision table; (b) normalizing the decision matrix through Euclidean norm; (c) creating a weightless scale; (d) calculating the positive ideal and the negative ideal; (e) calculating the distance or proximity to the positive ideal or the negative ideal, and (f) the Cli calculation, which indicates the proximity to the positive ideal and the distance from the negative ideal.

Data fuzzification

The main necessity in designing a fuzzy expert system is to select high-performance membership functions for linguistic variables and to define fuzzy input sets. In fuzzification, the input indices to the fuzzy variable are done by specifying the index classes in each class. The resulting function is called the Input Membership Function. Thus, by defining the membership functions, the membership grade of each point in the set can be determined. The membership grade of each point is a mapping of it in the fuzzy set, in the specified range (between zero and one), and based on the shape of the defined membership function. Thus, the membership grade ambiguity of a value is expressed quantitatively (mathematically). Dif-

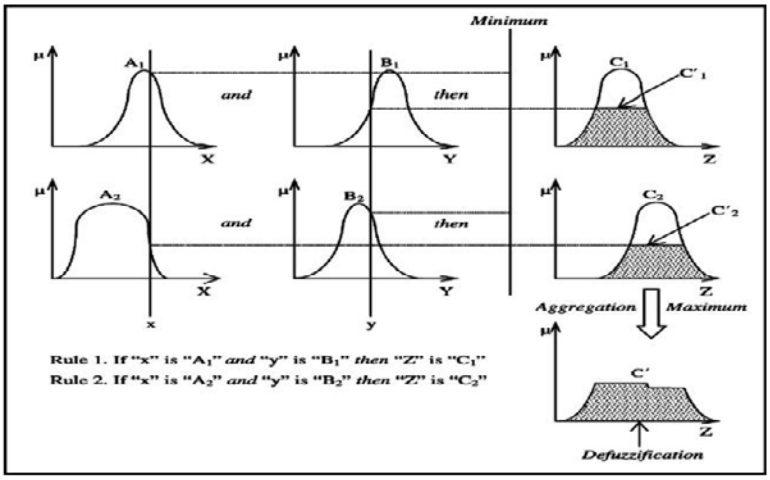

Figure 5. Mamdani fuzzy inference system simulation [5]

ferent types of membership functions have been used. These include triangular, trapezoidal, Gaussian, and sigmoid functions. In this research, a triangular function was selected according to the type of fuzzification. After determining the input and output indices, the fuzzy rules must be explained. These rules are explained based on the results. Finally, defuzzification is done by displaying the fuzzy connection between the variables. In this study, Mamdani fuzzy inference system was used. It should be noted that all steps of the fuzzy inference system were performed using the MATLAB software version R2018a. The implementation process of the Mamdani fuzzy inference system is shown in Figure 4.

Mamdani fuzzy inference system is preferred to other existing simulators due to its general acceptability and ease of use [3]. Fuzzy set output membership functions in Mamdani fuzzy inference must be de-fuzzy. This method increases the efficiency of the de-fuzzy process by reducing the required calculations. Minimum-Maximum, Maximum-Minimum-, Minimum-Minimum, and Maximum-Maximum are the most important methods used in Mamdani fuzzy simulation, and the maximum-minimum combination is commonly used [5]. A combination of maximum-minimum operators has been used in the Mamdani fuzzy simulation used in this research. Figure 5 shows Mamdani fuzzy inference system simulation.

This image compacts all operations from fuzzification to defuzzification. The flow of information starts from the left, and after processing each rule, the outputs on the right are combined, and the final output is generated. Fuzzy inference system decision-making is based on the rules applied by experts. The rules consist of two parts (if-then) and in (if), the input is defined. The triangular function was also used to determine the membership function. Fuzzy rules were compiled in the system rules database in MATLAB software. Finally, the fuzzy inference system was implemented by presenting the fuzzy connection model created between the variables.

3. Results

Since the methods of dealing with oil pollution in the soil depend to some extent on soil properties, the physicochemical and biological parameters of the soil in the area of this oil pump station were measured, the results of which are shown in Table 1. Pollution to total petroleum hydrocarbons was at a significant level. The status of other parameters in the soil of the study area was also determined.

In order to prioritize the identified options to determine the ideal method for dealing with oil pollution in the soil, multi-criteria decision-making techniques were used. Its purpose is to compare the decision-making results of the fuzzy inference system with the prioritization done by ten experts (five faculty members in the Department of Environment and five environmental experts in the National Iranian Oil Company). For this purpose, the main criteria were prioritized by the AHP multi-criteria decision-making technique in the first step. Accordingly, achieving prior use for soil weighing 0.273573 was determined as the most important criterion for prioritizing and determining the ideal method to deal with oil pollution. Execution cost with a weight of 0.172331, environmental effects with a weight of 0.157001, fit to the soil type with a weight of 0.141608, effects on the environment after disposal with a weight of 0.139351, and health effects on humans with a weight of 0.116135 were prioritized as other criteria. Also, the biological extraction method with a weight of 0.079977 has been determined as the most desirable method to deal with oil pollution in the soil in the area of this oil center. The results of prioritizing the main criteria of methods to deal with oil pollution in the soil based on the AHP method are shown in Table 2. Then the multi-criteria decision-making technique (Topsis) was used to prioritize the options. The decision matrix for prioritizing options is presented in Table 3. Also, the calculation of proximity to the positive and negative ideal solution and the ranking of options in the TOPSIS method is presented in Table 4.

Based on the multi-criteria decision-making technique results, bio-extraction with a coefficient of the proximity of 0.9335 was determined as the best method to deal with oil pollution in the soil of this oil pump station. Other biological methods, such as plant stabilization, bio-ventilation, and bio-stimulation were selected as ideal to deal with soil oil pollution by considering proximity coefficients 0.901.

Prioritize options using a fuzzy inference system

The first step in a fuzzy inference system is to define the input and output indices and their fuzzy equivalents. Fuzzy indices, classes, and their equivalents are shown in Table 5 and Figures 6 and 7. Index classes are determined based on the intuitive method.

Inference

The most important part of a fuzzy inference system is building the rule base. The purpose of writing these rules is to define different and varied statements obtained by combining different probabilities defined for each index (inputs and outputs). Conditional sentences define these statements (if ..... then ....). The criterion for decision-

Table 1. Soil properties of oil pump station area (Source: present research)

Sample Parameter	Soil 1	Soil 2	Soil 3	Soil 4	Soil 5	Soil 6	Soil 7
pH	7.04	7.35	7.23	7. 34	7.35	7.50	6.85
TDS	3.75	2.41	1.78	1.73	1.41	1.41	0.9586
Porosity	48.81	51.09	50.36	48.89	55.31	53.25	65.55
EC (µs /s / cm)	95.93	75.09	68.04	63.54	44.33	44.89	69.76
OC (%)	8.75	5.752	2.35	2.31	1.378	2.78	1.284
TPH (ppm)	1001	656	689	705	603	530	412
HPC (microbial population)	1×10^2	0.9×10^2	$0.0/7 \times 10^2$	$0/7 \times 10^2$	0.6×10^2	0.4×10^2	0.4×10^2
Apparent weight (g/cm^3)	1.40	1.49	1.38	1.32	1.31	1.40	1.38
Actual weight (g/cm^3)	2.63	2.64	2.74	2.70	2.74	2.74	2.73

making is based on if-then, here, "if" is called first, and "then" is called result.

The number of rules required for a fuzzy inference system depends on the number of classes in each index and is calculated by the following equation (Equation 2):

$$2.\ I = K1 \times \ldots \times K2 \times Kn$$

In this equation, I indicates the number of rules, n is the number of indexes, and k is the number of classes of each index. Given that six input indices and four classes are defined in each index, 4096 fuzzy rules were designed using MATLAB software (Figure 8).

Defuzzification

The final result of the inference process is a fuzzy output. It is necessary to return the output from the fuzzy state to a crisp value. This part of the inference process, known as defuzzification, is a unit that acts as a function of a fuzzy set to a crisp value. Many different methods have been developed for defuzzification of the inference process output, such as the center of gravity, the center of sets, height, the center of the largest surface, and maximum mean, which used the center of gravity in this study method. The fuzzy connection created between the input and output indices is shown in Figure 9.

The results of the prioritization of options in the fuzzy inference system have differences with multi-criteria decision-making techniques, which is probably due to differences in the definition of fuzzy rules. In this method, landfarming with a membership grade of 0.071 to a completely desirable set has been determined as the best method to deal with oil pollution in the soil. The fuzzy inference engine acts as a calculator and, based on fuzzy rules, determines the membership of the options to each set (Table 6).

Table 2. Results of prioritizing the main criteria of methods to deal with oil pollution in soil

Option Name	Weight
Achieve prior use for soil	0.273573
Execution cost	0.172331
Environmental effects	0.157001
The fit of the method with the soil type	0.141608
Effects on the environment after disposal	0.139351
Health effects on humans	0.116135

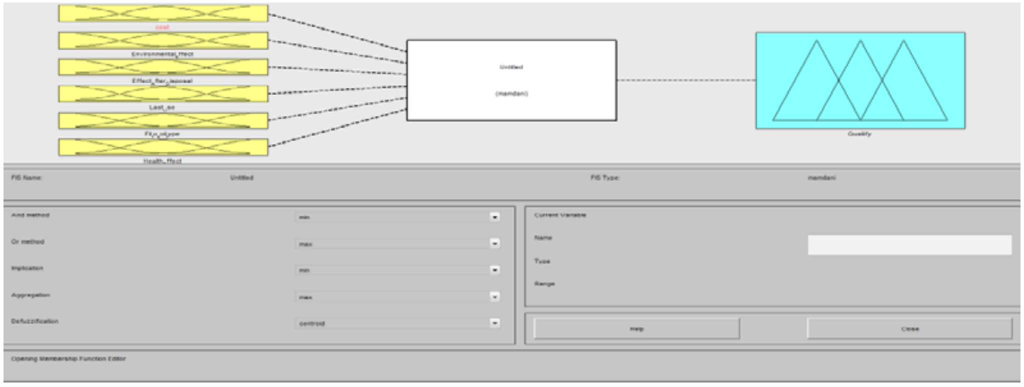

Figure 6. Creating initial input and output indices in the MATLAB software

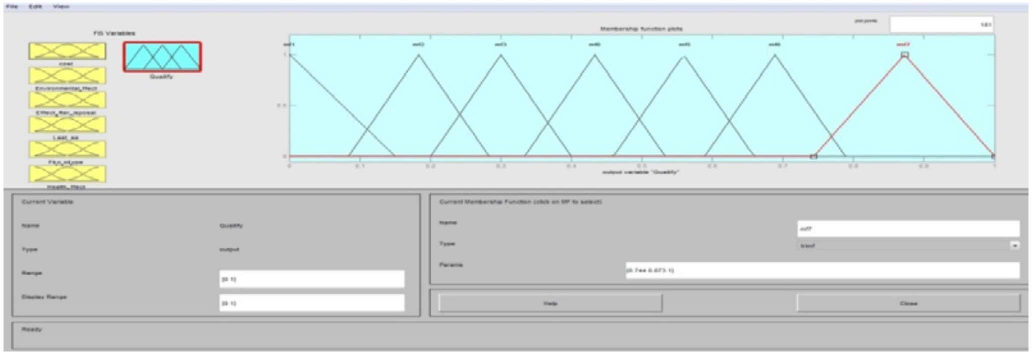

Figure 7. Defined membership functions and fuzzy mapping

4. Discussion

Decision-making in environmental management based on the collected information is one of the problems of environmental engineers [21, 22]. Various methods have been developed to quantify information and facilitate decision-making. However, it is difficult for machines to make decisions for reasons, such as multiple criteria, such as economic costs, social outcomes, efficiency, time, etc., to reach the stage where machines (mathematical methods) can be the optimal output and management decision in the field of environment. Further research should be

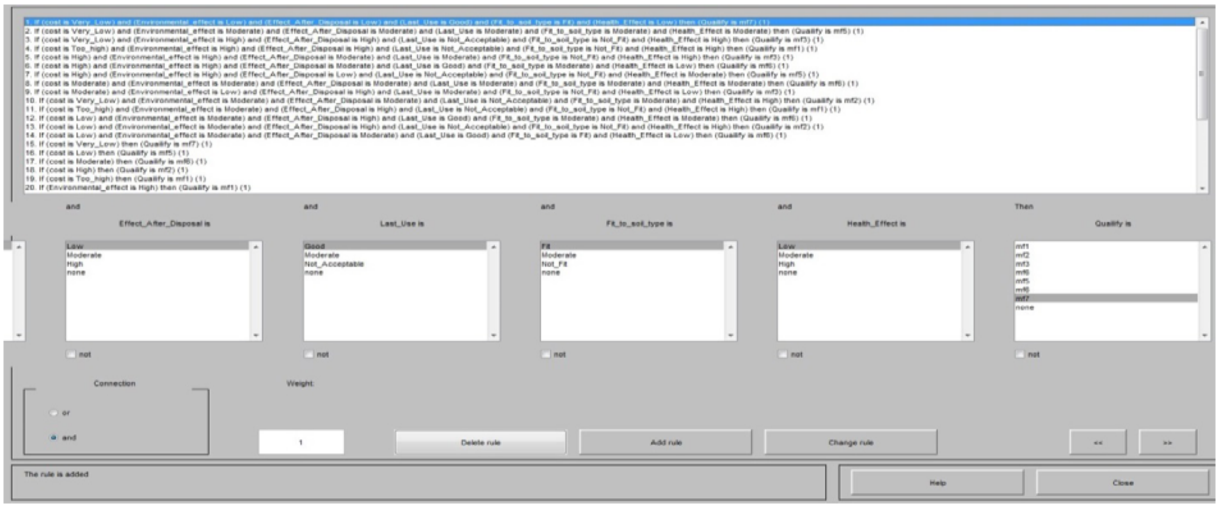

Figure 8. Building a database of rules in MATLAB software for the present study

Table 3. Decision matrix for prioritizing options in TOPSIS method

Matrix	Achieve Prior Use for Soil	Cost of Implementation	Environmental Effects	The Fit of the Method With Soil Type	Effects on the Environment After Disposal	Health Effects on Humans
Land-farming	6	5	7	7	7	8
Biological extraction	7	7	9	8	8	9
Bio-ventilation	6	8	8	7	8	8
Plant stabilization	7	7	8	8	8	8
Root decomposition	5	8	8	8	8	8
Plant decomposition	6	5	8	8	8	8
Plant evaporation	7	7	7	8	7	8
Bio-stimulation	7	7	8	8	8	7
Bio-sparing	6	3	7	8	7	6
Biological masses	2	5	6	7	6	4
Soil washing	4	2	2	4	2	2
Chemical oxidation	6	3	3	4	3	2
stabilization	1	4	3	7	3	7
Combustion	1	6	1	5	1	1
Heating (evaporation with temperature change)	2	1	4	5	4	4
Supercritical steam extraction	3	4	4	5	4	4
Electro-kinetics	5	2	3	6	3	5
Mechanical handling and burial	1	2	4	9	4	6
Criterion type	Positive	Positive	Positive	Positive	Positive	Positive
Standard weight	0.273573	0.172331	0.157001	0.141608	0.139351	0.116135

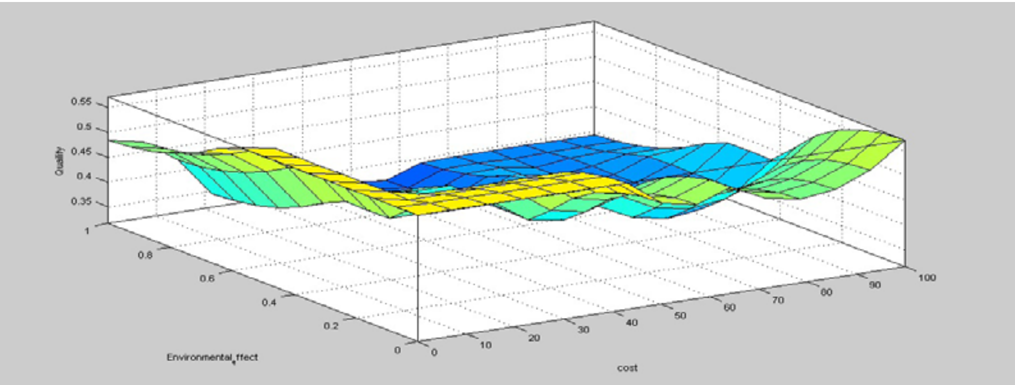

Figure 9. The fuzzy connection created between input and output indices

Table 4. Calculating the proximity to the positive and negative ideal solution and the ranking of options

Result	Proximity Coefficient
Biological extraction	0.9335
Plant stabilization	0.901
Bio-ventilation	0.887
Bio-stimulation	0.8724
Plant evaporation	0.854
Root decomposition	0.8233
Plant decomposition	0.779
Land-farming	0.7488
Bio-sparing	0.6352
Biological masses	0.4697
Chemical oxidation	0.4219
Electro-kinetics	0.3993
Supercritical steam extraction	0.3841
Stabilization	0.3492
Mechanical handling and burial	0.3159
Combustion	0.277
Heating (evaporation with temperature change)	0.2727
Soil washing	0.2646

done applying mathematical methods, such as fuzzy logic in environmental management. Currently, the main problem in applying mathematical methods to environmental management decisions is that most of the criteria cannot be easily condensed and quantified in a single unit [21]. For example, in the cost criterion of implementing each method of cleaning oil pollution in the soil, the calculation of the results of previous research has been the basis. However, based on economic and even political factors, the cost of implementation in different countries or even different regions can be different. On the other hand, accurate calculation of implementation costs for each method requires separate research. In other criteria, determining the level of desirability is based only on expert opinions, and it is often not possible to rank based on validated data.

Ma et al. [21] also mentioned the impossibility of creating data density in environmental decision-making as one of the most important drawbacks of these methods in environmental management. Jamshidi et al. [22] proposed using a combination of standardized data and environmental measurements to construct fuzzy rules for environmental decisions, such as waste disposal. The results of using fuzzy inference systems in decision-making in this research and its overlap with other methods used in research (AHP and TOPSIS) in prioritizing options for management decisions showed that fuzzy inference engine could be used as an intelligent decision system used. Balioti et al. [23] described the combination of multi-criteria decision-making techniques with fuzzy logic as a more effective way to achieve optimal environmental decision-making. The interplay of goals between environmental ethics, economics, and other criteria has made applying these methods difficult. Therefore, this research proposes to create a database to facilitate the possibility of quantifying data [24-27].

Table 5. Fuzzy indices, classes, and their fuzzy equivalents

Input Indices	Class	Fuzzy Equivalent	Data Mapping
Cost of implementation	Less than $ 10 (square meters)	Very little	20-0
	10-30 $	Low	35-15
	30-60 $	Medium	50-30
	60-100 $	Much	65-45
	More than 100 $	Very much	100-60
Environmental effects	-	Low	0.4-0
	-	Medium	0.9-0.1
	-	Much	1- 0.6
Effects on the environment after disposal	-	Low	0.4-0
	-	Medium	0.9-0.1
	-	Much	1-0.6
Achieve prior use for soil	-	Suitable	0.4-0
	-	Acceptable	0.9-0.1
	-	Inappropriate	1-0.6
The fit of the method with the soil type	-	Fit	0.4-0
	-	Low fit	0.9-0.1
	-	Non-fit	1-0.6
Health effects on humans	-	Low	0.4-0
	-	Medium	0.9-0.1
	-	Much	1-0.6
The desirability of the method	-	Completely N0n-Optimal	0.15-0
	-	N0n-Optimal	0.3-0.1
	-	Very low Optimal	0.4- 0.2
	-	Moderate Optimal	0.55-0.35
	-	Relatively Optimal	0.65-0.45
	-	Optimal	0.8-0.6
	-	Absolutely Optimal	0.1-0.75

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Table 6. Comparison of fuzzy inference system results with multi-criteria decision-making methods

Method	Topsis	AHP	Membership in Fuzzy Set	Membership Grade (Non-Fuzzy Map)
Land-farming	0.7488	0.055385	Completely desirable	0.71
Biological extraction	0.9335	0.079977	Completely desirable	0.63
Bio-ventilation	0.887	0.070111	Completely desirable	0.62
Plant stabilization	0.901	0.074451	Completely desirable	0.25
Root decomposition	0.8233	0.063032	Absolutely desirable	0.08
Plant decomposition	0.779	0.066342	Desirable	0.8
Plant evaporation	0.854	0.068363	Desirable	0.3
Bio-stimulation	0.8724	0.070629	Relatively desirable	1
Bio-sparing	0.6352	0.05466	Relatively desirable	0.74
Biological masses	0.4697	0.052088	Relatively desirable	0.36
Soil washing	0.2646	0.039912	Moderate desirability	0.85
Chemical oxidation	0.4219	0.04368	Relatively low desirability	0.32
Stabilization	0.3492	0.042779	Relatively low desirability	0.45
Combustion	0.277	0.045516	Relatively low desirability	0.6
Heating (evaporation with temperature change)	0.2727	0.042824	Undesirable	0.17
Supercritical steam extraction	0.3841	0.042683	Undesirable	0.62
Electro-kinetics	0.3993	0.044492	Completely undesirable	0.46
Mechanical handling and burial	0.3159	0.043075	Completely undesirable	0.69

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5. Conclusion

The environment is one of the areas that has not yet benefited much from mathematical methods in decision-making. It is suggested to use fuzzy logic in decision-making for other environmental areas and, if the desired results are obtained, create comprehensive systems in national and international organizations to achieve the ideal decision in changing conditions. This measure can significantly reduce the rate of human error in environmental decisions.

Ethical Considerations

Compliance with ethical guidelines

There were no ethical considerations to be considered in this research.

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Authors' contributions

All authors equally contributed to preparing this article.

Conflict of interest

The authors declared no conflict of interest.

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