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Research Article:

Assessment of water quality index of Qilyasan Stream in Sulaimani city, Iraq, using Fuzzy Logic Method

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Abstract

The aim of this study is to propose an index of Fuzzy Water Quality Index (FWQI), to assess the water quality of Qilyasan Stream. The suggested fuzzy index incorporates the specified thresholds for quality indicators, which are primarily taken from Iraqi water laws. Eighteen parameters are combined in the suggested index including temperature, pH, alkalinity, total hardness, EC, TDS, TSS, turbidity, NO_3, SO_4, PO_4, BOD, COD, DO, Pb, Cd, Zn, and Cu. MATLAB R2022b was used to develop the fuzzy model. Five stations in the stream were selected for sampling. These membership-grade classifications can be a useful tool for decision-making, helping to designate a progressive quality sub-objective to each stream segment. The obtained results from FWQI were compared with Weighted Arithmetic Water Quality Index (WAWQI). The results revealed that the FWQI at St 1, St 2, and St 5 is (9.78), and at St 3, and St 4 is (10.1), the quality ranking of all stations was very poor, and WAWQI shows that all stations were unsuitable reusing purposes. The proposed approach shows a convenient tool for monitoring of stream waters.

1. Introduction

Large volumes of environmental pollutants are discharged into the air, water, and land each year. Negatively affecting human health, wildlife, and ecosystem. Surface water bodies including rivers, lakes, reservoirs, and oceans are primarily contaminated by industrial and urban effluent [1]. Concerns about the water quality have been voiced globally in recent years. Standards have been set by authorities to compare with. Indexes have been created to assess the water quality of water bodies. The goal of water quality indices is to reduce a number of complex indications to a single, easily understood value that characterizes the water quality Due to the rapid rate of population increase, wastewater disposal has become a major concern in many developing nations. Since Sulaymaniyah lacks a wastewater treatment plant, the sewage is dumped untreated into the Qilyasan Stream of a specific source. Numerous water quality indices are currently in use worldwide, including the U.S. National Sanitation Foundation Water Quality Index (NSFWQI); the Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI); the British Columbia Water Quality Index (BCWQI), and the Oregon Water Quality Index (OWQI). These indices are based on various indicators and aggregation techniques [2]. Conventional water quality indices have a common drawback in that they rely on human skill with subjective and unclear data, which could lead to a multitude of problems when assessing water quality. Another significant issue is that concentrations of quality indicators, regardless of how near or far from the limitations they are, have an equal effect on the final score and may belong to the same classes [2]. Fuzzy logic, initially presented by Zadeh in 1965, is frequently employed as a potent formalism in environmental evaluation and assessment, such as in matters pertaining to air or water pollution, in order to address ambiguity and uncertainties. According to Asmaa [2], fuzzy logic has demonstrated promising results in the modeling of novel water quality indexes, FWQI handles uncertainty, subjectivity, and the complexity of water quality data. In order to create a water quality index for the Sorocaba River in São Paulo, Brazil, Roveda [3] used fuzzy inference system (FIS), they have considered nine water quality metrics based on this inference framework. Compared to WQI, the fuzzy logic (FL) approach proved to be more successful. Quiñones-Huatangari [4], created a fuzzy logic-based WQI that made it possible to estimate the water quality of Peru's Utcubamba River, throughout sixteen locations along the river. They have used nine water quality parameters in their model. To classify the water quality state of the Gajahwong River in Yogyakarta, Indonesia, Novita [5], set out to create a FL system, using eleven water quality parameters, and Mamdani FIS model to state the quality of the river. Salam [6] sought to create a new water quality index based on FL for routine evaluation of river water quality for drinking purposes. Given their importance to Iraqi waters, four water quality criteria were considered, Mamdani FIS were used. They obtained the lake water quality in accordance with the water quality classification criteria. Asmaa [2] used FL method to suggest a new river water quality indicator in Morocco. The suggested index gives a numerical value for the assessed water quality by combining six indicators (DO, BOD, COD, NH_4, TP, and FC). The resulting classifications were then contrasted with Morocco's current standard physicochemical water quality index. Fatemeh [7] used FL method to assess the quality of Zayandehrud River in Iran province of Isfahan. In their study they have used nine sampling stations. Six metrics were used to assess the water quality for industrial use (pH, TH, TA, SO_4, Cl, and TDS). Using fuzzy logic, Adem [8] developed an index model for assessing the quality of water quality classification in Turkey. A number of heavy metals, including Cu, Zn, Mn, Pb, Ni, Cd, and Fe, that were gathered from five monitoring sites in the Karasu River. The main objective of this research is to find the WQI of Qilyasan stream using fuzzy logic water quality index (FWQI), and assessing the impact of pollutants in the discharged area, this method is used for the first time for Qilyasan stream, by using eighteen parameters, and group them into five groups to assess the WQI at five stations along the stream. The water quality of Qilyasan stream is becoming more of a concern due to the substantial number of contaminants that are released into these ecosystems, frequently without any kind of treatment.

2. Materials and methods:

Data, information, and GIS maps of the research area were gathered through site visits and interviews with authorities. The coordinates of five stations were taken using GPS. Samples were collected for two seasons (wet, and dry), from five stations along the stream.

2.1 The Study Area:

Qilyasan stream is located west of Sulaymaniyah city in Iraq and it is situated at an elevation of 656-787 m amsl. Its coordinates are 35 34 44.8 north and 45 22 20.3 east [9]. Sulaymaniyah city consists of four suburbs; Sulaymaniyah Center, Bakrajo, Raparin, and Tasluja [10]. The city's sewer system is combined, and the main trunk sewers are concrete box sewers. Thirty-two major exits of the collected sewage release into open areas in the city and most of them into Qilyasan stream without any treatment [10].

2.2 Data Collection:

Site visit has been done in 9th November 2024, at 10:20 AM. The information, and data obtained from the governmental institutions were GIS maps, statistical data and others. On the other hand, some data were taken from other researches and thesis.

2.3 Sampling Methods:

The water samples were collected from five stations along Qilyasan stream for two seasons (wet, and dry) using grab sampling technique. The First site St1 located at 35°33'06.0" N (35.5516660), 45°22'20.1" E (45.3722500), near Qilyasan Bridge, Second site St2 located at 35°32'52.0" N (35.5477850), 45°22'27.0" E (45.3741760) in Kostay Cham, near Kalleh dairy factory, St3 located at 35°31'20.2"N (35.5222770), 45°22'27.6"E (45.3743330) between Kani Goma and Mahwi Nwe sector, St4 located at 35°30'43.7" N (35.5121390), 45°22'37.2"E (45.3770000) between Kani Goma Prison, and Amr concrete company, near this site there is a Gravel and silt washing plant, St5 located at 35°28'46.5" N (35.4795830), 45°25'37.2"E (45.4270000) in Tanjaro, Qaradagh Road, opposite Nzho oil and natural gas company. **Figure (2)** illustrates the sampling station along Qilyasan stream.

2.4 Parameters:

Eighteen parameters were selected including temperature, pH, alkalinity, total hardness, electrical conductivity (EC), total dissolved solids (TDS), total suspended solids (TSS), turbidity, nitrate (NO_3), sulphate (SO_4), phosphate (PO_4), biological oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen (DO), lead (Pb), cadmium (Cd), Copper (Cu), and zinc (Zn). **Table (1)** Shows the allowable ranges of the parameters in stream water. All the parameters have been measured, temperature has been measured using Thermometer, Multiparameter device used for measuring pH, EC, and TDS, Turbidimeter. Lovibond used for measuring turbidity, Shimadzu UV Visible 1800 Spectrophotometer used to measure NO_3, SO_4, and PO_4, BOD Analyzer BD 600 Lovibond used to measure BOD, COD Meter MD 200 Lovibond used to measure COD, DO Meter YSI used to measure DO, Atomic Adsorption Shimadzu 700 000 used to measure Pb, Cd, Zn, and Cu. Gravimetric Analysis method used to measure TSS, and Titration method used to measure alkalinity, and total hardness.

2.5 The Fuzzy Model:

In this work two layers have been set to assess the quality of Qilyasan Stream, first layer (input, output) is to assess the quality of each group and second layer (input, output) is to assess the quality of each station, the output of the first layer is the input for the second layer. In the first layer all the eighteen parameters have been grouped into five groups according to the relation and dependency of each parameter on the other parameters as shown in **Table (2)**, $Group_1$ include (pH, alkalinity, and total hardness), $Group_2$ include (EC, TDS, TSS, and turbidity), $Group_3$ include (NO_3, SO_4, and PO_4), $Group_4$ include (temperature, BOD, COD, and DO), and $Group_5$ contain (Pb, Cd, Zn, and Cu). Fuzzy sets and linguistic variables have been set for each parameter, trapezoidal and triangular membership function have been used in this work, the range and fuzzy sets of all Groups are shown in **Table (2)**, the fuzzy input model of all parameters and five linguistic variables have been used for the output of the Groups; Excellent, Good, Average, Poor, and Very Poor, as shown in **Table (3)**. All the membership functions for input and output variables are shown in **Figure (3)**. Rules have been set using "and" operator. Defuzzification process is done using centroid method, **Figure (4)** shows the defuzzification process of the work. In the second layer the output of each group has been used as an input. The following Figure (1) shows the main steps in FWQI.

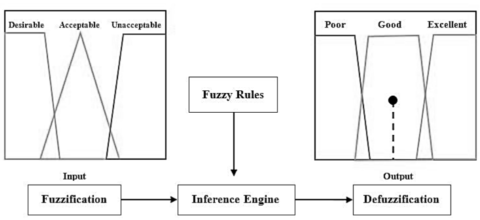

Figure (1): The main steps of FWQI.

Fuzzy Logic theory:

Zadeh [11] introduced fuzzy logic theory, which can be used to estimate parameters that are inherently imprecise. Fuzzy sets can therefore deal with ambiguity or uncertainties in the parameters relating to water quality. The Fuzzy inference system provides a basis for making decisions.

Membership Functions:

Membership function values in fuzzy sets fluctuate between 0 and 1, in contrast to crisp sets, which are represented by the binary values (0 or 1) of membership functions (MFs). The inherent unpredictability is reflected in this seamless boundary transition based on the properties of the data, several membership function types such as; Gaussian, triangular, trapezoidal, sigmoid, etc. can be chosen. The link between an uncertain number x and its corresponding membership function μ, which ranges from 0 to 1, is described by a fuzzy set.

$A = \{x, \mu_A(x) \mid x \in U\}$ **(1)**

where U is a discourse set universe and μA(x) is the membership function of x in A.

Fuzzy Set Operators:

The operators of classical set theory are modified to fit fuzzy logic's unique membership functions, which only permit values between 0 and 1, making it simple to work with fuzzy sets [2]. The fuzzy set operators are union (OR), complement (NOT IN), inclusion, and intersection (AND). The membership functions for A and B are denoted by μ_A and μ_B, respectively. Likewise, the definition of the fuzzy intersection (AND) is:

$\mu_{A \cap B}(x) = \min[\mu_A(x), \mu_B(x)] =$
$\mu_A(x) \cap \mu_B(x)$, where $x \in X$ **(2)**

Fuzzy Inference Rules:

Fuzzy logic describes the links between a system's input and output variables using fuzzy set operators and if-then rules. A group of linguistic representations known as fuzzy rules specify how a fuzzy inference system need to decide whether to classify an input or regulate an output. One or more backgrounds make up a fuzzy rule, which is typically joined by linguistic operators like "and" or "or". In the present work linguistic variables were connected using "and" operator.

Basic structure of the Fuzzy Inference System:

The FIS is an inference system based on the fuzzy sets, which sets input values to the output values. Three crucial processes are included in a FIS model:

Fuzzification is the process of converting crisp data, such as inputs and target vectors, into fuzzy sets and assigning membership functions. The Inference Engine of the FL model is made up of the fuzzy rules. Using fuzzy operators like AND, OR, NOT, and Prod, each rule joins the inputs to the goal vectors [12]. The inference engine combines the implication and aggregation processes to generate conclusions based on a mix of rules [13]. In this work for the first layer 297 rules, (27, 81, 81, 27, 81, 81) rules for Group (1, 2, 3, 4, and 5)

respectively, and for the second layer 3125 rules were used. Below are some examples of the rules for layers:
If (pH is Unacceptable-Low) and (Alkalinity is Unacceptable) and (TH is Unacceptable) then (Group_1 is Very_Poor).
If (EC is Unacceptable) and (TDS is Unacceptable) and (TSS is Unacceptable) and (Turbidity is Unacceptable) then (Group_2 is Very_Poor).
If (NO_3 is Unacceptable) and (SO_4 is Unacceptable) and (PO4 is Unacceptable) then (Group_3 is Very_Poor).
If (Temperature is Unacceptable-Low) and (DO is Unacceptable) and (BOD is Unacceptable) and (COD is Unacceptable) then (Group_4 is Very_Poor).
If (Pb is Unacceptable) and (Cd is Unacceptable) and (Zn is Unacceptable) and (Cu is Unacceptable) then (Group_5 is Very_Poor).
If (Group_1 is Very_Poor) and (Group_2 is Very_Poor) and (Group_3 is Very_Poor) and (Group_4 is Very_Poor) and (Group_5 is Very_Poor) then (Station is Very_Poor).

Defuzzification: this stage employs a defuzzification technique to convert the aggregation result into clear data. The most popular techniques for defuzzification are the bisector of area (BOA), center of area (COA), biggest of maximum (LOM), middle of maximum (MOM), and smallest of maximum (SOM) [12].

3. Model Validation:

Any type of modeling must be evaluated using model validation, which is frequently used to measure the strength of correlations between model inputs and outputs. In this work measuring WQI has been used to assess the model validation to input parameter values in water quality model. Weighted Arithmetic Water Quality Index (WAWQI) has been used for model validation, and the two results compared with each other. **Equation (3)** is used to calculate this approach [14].

$$WAWQI=\frac{\sum Wiqi}{Wi} \dots \textbf{(3)}$$

where the water's quality is indicated by the WQI, which ranges from 0 to 100 as shown in **Table (7)**; For each parameter, qi stands for a relative value of the water quality; i stands for the number of parameters that are taken into account; Wi is a factor that assesses a parameter's significance in determining the WQI index (relative weight).

4. Results and Discussion:

The water quality of Qilyasan Stream at five stations has been assessed using FWQI. Samples have been collected, and tested for both seasons, the results are shown in **Table (4)**, All the eighteen parameters have been tested at all five stations, for St_1 (pH, EC, TDS, SO_4, COD, Pb, and Zn), for St_2 (pH, EC, TDS, SO_4, COD, Pb, Zn, and Cu), for St_3 (pH, total hardness, EC, TDS, SO_4, COD, Pb, and Zn), for St_4 (pH, total hardness, EC, TDS, SO_4, COD, and Pb) and for St_5 (pH, EC, TDS, SO_4, and Pb) for wet season, in dry season for St_1 (pH, TH, EC, TDS, NO_3, SO_4, COD, Pb, Zn, and Cu), for St_2 (pH, TH, EC, TDS, SO_4, COD, Pb, Zn, and Cu), for St_3 (pH, EC, TDS, SO_4, COD, Pb, Zn, and Cu), for St_4 (pH, EC, TDS, SO_4, COD, and Pb), and for St_5 (pH, EC, TDS, SO_4, Pb, and Cu) for dry season were within the limits which set by the standards. Quality of Station St_1, St_2, and St_5 was 9.78, the quality of Station St_3, and St_4 was 10.1, for wet season, and 9.78 at St_1, St_2, St_3, and St_5, and 10.1 at St_4 for the dry season. according to the fuzzy classifications, the results from all stations are considered "Very Poor" (final class). The calculated FWQI according to FIS of $Group_1$, $Group_2$, $Group_3$, $Group_4$, $Group_5$, Stations, and Stream are given in **Table (5)**. The results of model validation using WAWQI were (158.271046, 183.56332, 203.80886, 263.7766544, and 422.101687) for wet season, and (130.491989, 143.08417, 167.12177, 235.5528751, and 286.742535) for dry season, the ranking of all stations were "Unsuitable for reusing purpose", as shown in **Table (7)**. The two indices showed the same results (lowest class), therefore, this results due to the discharged wastewater of Sulaymaniyah city, which contains, hospitals, factories, domestic, and runoff wastewaters. On the other hand, the results from FWQI and WAWQI have been compared. The quality of Qilyasan stream is very poor and needs to be treated using a treatment plant using (physical, chemical, biological, and advanced) treatment processes.

5. Conclusions:

Fuzzy Water Quality Index is proposed for the evaluation of water quality of Qilyasan Stream at five stations. Eighteen indicators (pH, alkalinity, total hardness, EC, TDS, TSS, turbidity, NO_3, SO_4, PO_4, temperature, BOD, COD, DO, Pb, Cd, Zn, Cu) were used to assess the quality of the water. The FWQI results ranged between 9.78 to 10.1 at all stations during wet, and dry season, all the results classified as "Very Poor". WAWQI ranged between 130.491989 to 422.101687 during wet and dry season at all stations, all the results were classified as "Unsuitable for reusing purposes". The results showed that the quality of Qilyasan Stream is very poor, and the wastewater needs to be treated before dumping into Qilyasan Stream. The suggested index can address the linguistic ambiguity and uncertainty that are specific to this environmental issue. In contrast to the traditional index, the new fuzzy index enables both quantitative and qualitative interpretation of the results in addition to membership grades. Because specialists can characterize a sampling station's quality condition as being closer to its upper or lower limit, it also enables a better analysis. A comparison between FWQI and WAWQI was carried out, Because the suggested index makes use of quality thresholds from Iraqi standards, it has been demonstrated to be more precise. The traditional score falls short of local health experts' understanding of industrial and agricultural pollutants.

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[19] جمهورية العراق ، قانون رقم (٢) لسنة ٢٠٠١ المعدل لقانون المُحددات البيئية لنظام صيانة الانهار والمياه العمومية من التلوث المرقم (٢٥) لسنة ١٩٦٧ ، جريدة الوقائع العراقية ، العدد (٣٨٩٠) في ٢٠٠١/٦/٨ ، العراق ، ٢٠٠١ .

طريقة المنطق الضبابي في إيجاد مؤشر جودة المياه في مجرى نهر قلياسان في مدينة السليمانية، العراق

المستخلص:

نظرا للمعدل السريع للزيادة السكانية، أصبح التخلص من مياه الصرف الصحي مصدر قلق كبير في العديد من الدول النامية. نظرا لافتقار مدينة السليمانية إلى محطة لمعالجة مياه الصرف الصحي، يتم إلقاء مياه الصرف الصحي دون معالجة في مجرى قلياسان. الهدف من هذه الدراسة هو اقتراح مؤشر جديد يسمى مؤشر ممداني لجودة المياه الضبابية(MFWQI) ، لتقييم جودة المياه في مجرى قلياسان. يشتمل المؤشر الغامض المقترح على العتبات المحددة لمؤشرات الجودة، والتي يتم أخذها بشكل أساسي من قوانين المياه العراقية. تم دمج ثمانية عشر مؤشرا في المؤشر المقترح بما في ذلك درجة الحرارة، ودرجة الحموضة، والقلوية، والعسر الكلي، والموصلية الكهربائية، ومواد الصلبة المذابة، ومواد الصلبة العالقة، والتعكر، والنترات، والكبريتات، والفوسفات، وBOD، وCOD، والأكسجين المذابة، والرصاص، والكادميوم، والزنك، والنحاس .تم استخدام MATLAB R2022bلتطوير النموذج الضبابي. ويمكن أن تكون هذه التصنيفات من الرتبة أداة مفيدة لاتخاذ القرارات، مما يساعد على تحديد هدف فرعي تدريجي للجودة لكل جزء من أجزاء النهر . تمت مقارنة النتائج التي تم الحصول عليها من MFWQI مع مؤشر جودة المياه الحسابي المرجح .(WAWQI) أظهرت النتائج أن FWQI في المحطة ١ والمحطة ٢ والمحطة ٥ هو (٩.٧٨)، وفي المحطتين ٣ و ٤ هو (١٠.١)، وكانت تصنيفات جودة جميع المحطات ضعيفة جداً، ويظهر WAWQIأن جميع المحطات غير مناسبة للشرب. المنهج المقترح يعتبر أداة ملائمة لمراقبة مياه الأنهار .

الكلمات المفتاحية:

إزالة الضبابية، المنطق الضبابي، دالة الانتماء(MF) ، مؤشر جودة المياه(WQI) ، مؤشر جودة المياه الحسابي الوزني(WAWQI)

Table (1): Water Quality Standards for The Eighteen Parameters in Stream.

No.	Parameters	Units	Range	Source
1	Temperature	° C	< 30	[15]
2	pH	_	6.5 – 8.5	[19]
3	Alkalinity	mg/l as CaCO3	< 200	[16]
4	Total Hardness	mg/l as CaCO3	< 300	[16]
5	EC	(μs/cm)	< 2250	[16]
6	TDS	mg/l	< 2500	[16]
7	TSS	mg/l	< 60	[16]
8	Turbidity	NTU	< 50	[17]
9	NO3	mg/l	< 15	[19]
10	SO4	mg/l	< 200	[19]
11	PO4	mg/l	< 0.4	[19]
12	BOD	mg/l	< 3	[19]
13	COD	mg/l	< 100	[18]
14	DO	mg/l	> 5	[19]
15	Pb	mg/l	< 0.05	[19]
16	Cd	mg/l	< 0.005	[19]
17	Zn	mg/l	< 0.5	[19]
18	Cu	mg/l	< 0.05	[19]

Table (2): Fuzzy Sets for the Eighteen Parameters (5 Groups) in Assessing Qilyasan Stream Water Quality.

Group No.	Parameters	Maximum Allowable	Fuzzy Range	Classifications	Membership Function	Fuzzy Coordinates
Group 1	pH	6.5 – 8.5	5 – 7	Unacceptable - Low	Trapezoidal	5 5 6.5 7
			6.5 – 8.5	Desirable	Triangular	6.5 7 8.5
			7 – 10	Unacceptable - High	Trapezoidal	7 8.5 10 10
	Alkalinity	< 200	< 200	Desirable	Trapezoidal	0 0 100 200
			150 - 350	Acceptable	Trapezoidal	150 200 300 350
			300 – 500	Unacceptable	Trapezoidal	300 350 500 500
	Total Hardness	< 300	< 325	Desirable	Trapezoidal	0 0 300 325
			275-625	Acceptable	Trapezoidal	275 300 550 625
			> 575	Unacceptable	Trapezoidal	575 600 800 800
Group 2	EC	< 2250	< 300	Desirable	Trapezoidal	0 0 200 300
			250 - 550	Acceptable	Trapezoidal	250 350 450 550
			500 – 1000	Unacceptable	Trapezoidal	500 650 1000 1000
	TDS	< 2500	< 600	Desirable	Trapezoidal	0 0 550 600
			550-2100	Acceptable	Trapezoidal	550 600 1900 2100
			> 1900	Unacceptable	Trapezoidal	1900 2000 2500 2500
	TSS	< 60	< 11	Desirable	Trapezoidal	0 0 9 11
			8 – 17	Acceptable	Trapezoidal	8 10 14 17
			14 – 600	Unacceptable	Trapezoidal	14 17 900 900
	Turbidity	< 50	< 6	Desirable	Trapezoidal	0 0 4 6
			5 – 50	Acceptable	Trapezoidal	5 25 35 50
			40 - 1000	Unacceptable	Trapezoidal	40 80 1000 1000
Group 3	NO3	15	< 10	Desirable	Triangular	0 0 10
			0 – 15	Acceptable	Triangular	0 10 15
			10 – 80	Unacceptable	Triangular	10 15 80
	SO4	< 200	< 200	Desirable	Trapezoidal	0 0 180 200
			170 – 210	Acceptable	Trapezoidal	170 185 200 210
			200 – 350	Unacceptable	Trapezoidal	200 205 350 350
	PO4	0.4	< 0.4	Desirable	Trapezoidal	0 0 0.3 0.4
			0.3 – 0.6	Acceptable	Trapezoidal	0.3 0.4 0.5 0.6
			0.5 – 50	Unacceptable	Trapezoidal	0.5 0.6 50 50
Group 4	Temperature	20 – 30 ° C	0 – 25	Unacceptable - Low	Trapezoidal	0 10 20 25
			20 – 30	Acceptable	Triangular	20 25 30
			25 - 35	Unacceptable - High	Trapezoidal	25 30 35 35
	BOD	< 3	1 – 3	Desirable	Triangular	1 1 3
			1 – 10	Acceptable	Triangular	1 3 10
			3 – 200	Unacceptable	Trapezoidal	3 10 200 200
	COD	< 100	<30	Desirable	Trapezoidal	0 0 20 30
			30 – 80	Acceptable	Trapezoidal	30 30 80 80
			> 80	Unacceptable	Trapezoidal	80 81 500 500
	DO	> 5	>7	Desirable	Trapezoidal	7 7 11 20
			4 – 7	Acceptable	Triangular	4 5 7 -
			< 5	Unacceptable	Trapezoidal	0 1 2 5
Group 5	Pb	0.05	< 0.03	Desirable	Triangular	0 0 0.03
			0 – 0.1	Acceptable	Triangular	0 0.03 0.1
			0.03 – 1	Unacceptable	Triangular	0.03 1 1
	Cd	0.005	< 0.003	Desirable	Triangular	0 0 0.003
			0 – 0.01	Acceptable	Triangular	0 0.003 0.01
			0.003 - 0.1	Unacceptable	Triangular	0.003 0.1 0.1
	Zn	0.5	< 0.3	Desirable	Triangular	0 0 0.3
			0 – 1	Acceptable	Triangular	0 0.3 1
			0.3 – 5	Unacceptable	Triangular	0.3 1 5
	Cu	0.05	< 0.03	Desirable	Triangular	0 0 0.03
			0 – 0.1	Acceptable	Triangular	0 0.03 0.1
			0.03 – 1	Unacceptable	Triangular	0.03 1 1

Table (3): The Output Results of the FWQI Model in Layer One, Two, and Three**.**

Groups	Fuzzy Range	Classifications	Membership Functions	Fuzzy Coordinates
For all Groups	0 – 22	Very Poor	Trapezoidal	0 0 18 22
	18 – 42	Poor	Trapezoidal	18 22 38 42
	38 – 62	Average	Trapezoidal	38 42 58 62
	58 – 82	Good	Trapezoidal	58 62 78 82
	78 – 100	Excellent	Trapezoidal	78 82 100 100

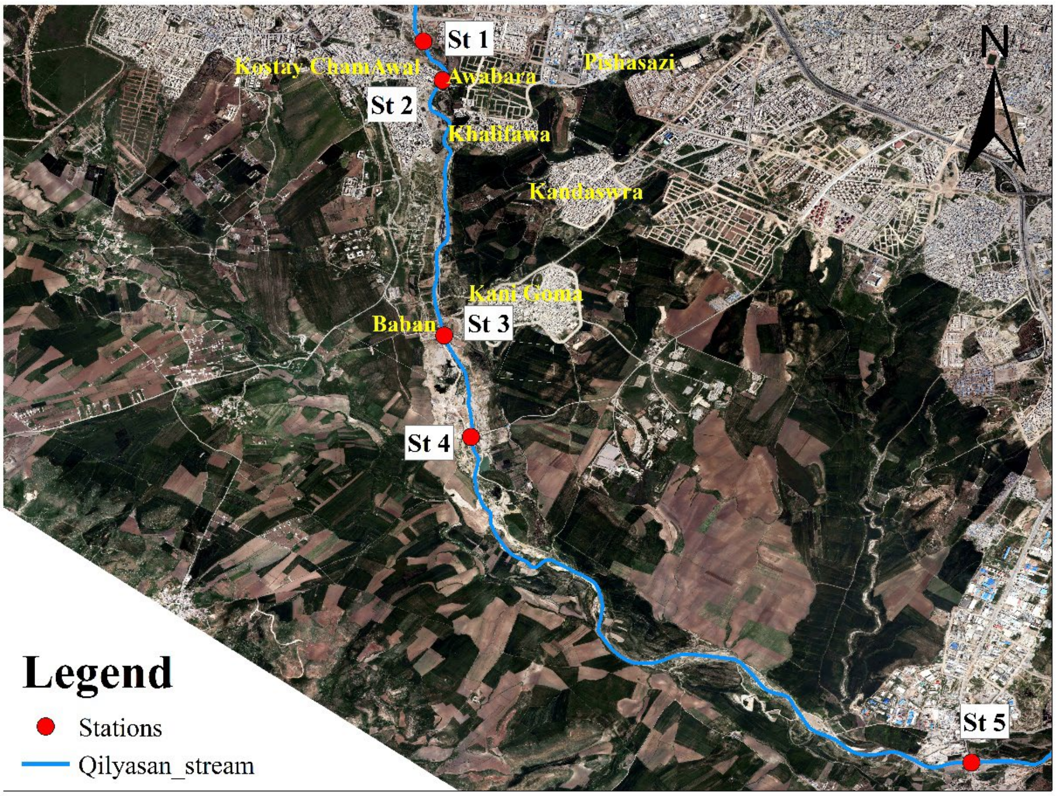
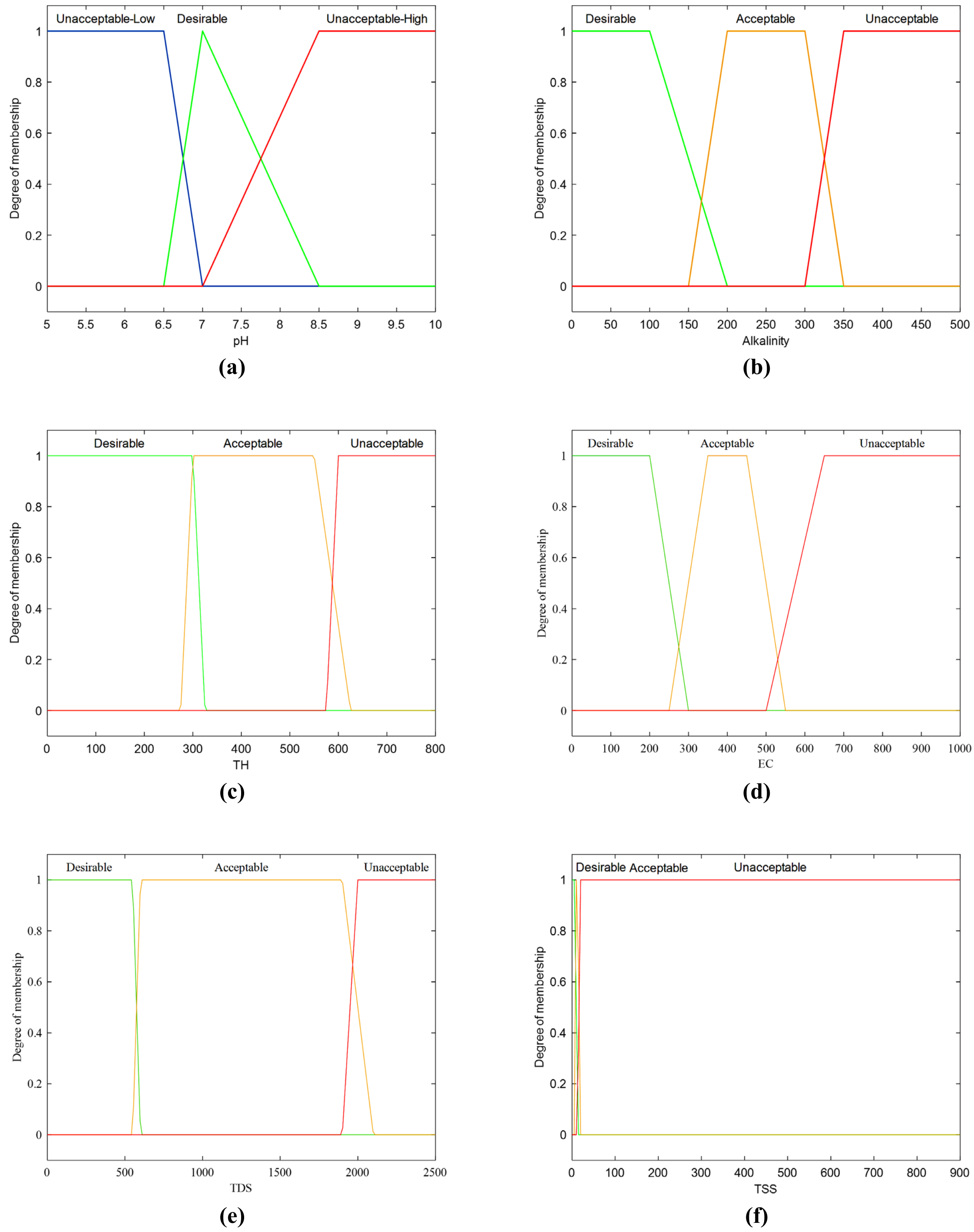
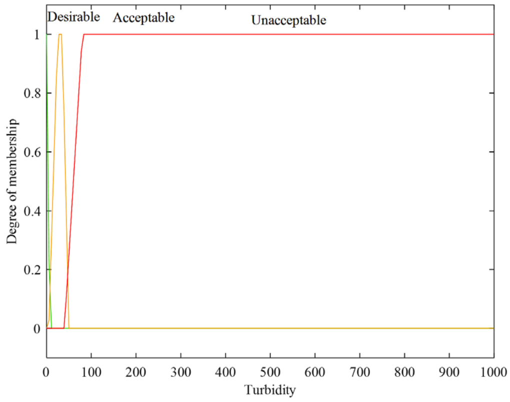
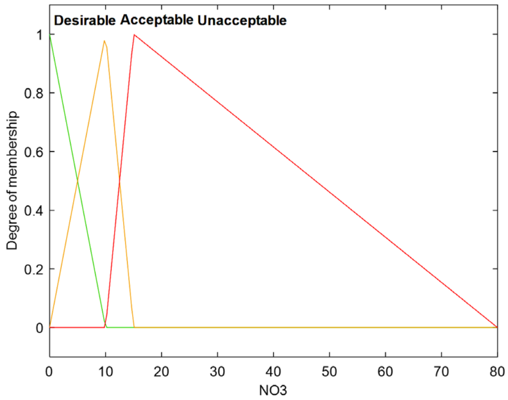


Figure (2): the Study Area, Locations of the Five Stations Along Qilyasan Stream, Sulaymaniyah, Iraq**.**

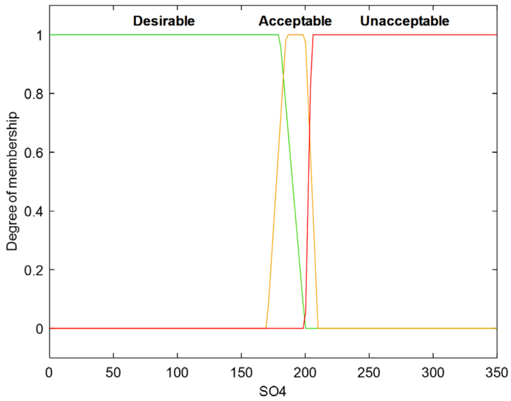

Unacceptable-Low
Desirable
Unacceptable-High
Degree of membership
pH
(a)
Desirable
Acceptable
Unacceptable
Degree of membership
Alkalinity
(b)
Desirable
Acceptable
Unacceptable
Degree of membership
TH
(c)
Desirable
Acceptable
Unacceptable
Degree of membership
EC
(d)
Desirable
Acceptable
Unacceptable
Degree of membership
TDS
(e)
Desirable Acceptable
Unacceptable
Degree of membership
TSS
(f)


Desirable
Acceptable
Unacceptable
Degree of membership
Turbidity
0
0.2
0.4
0.6
0.8
1
0
100
200
300
400
500
600
700
800
900
1000

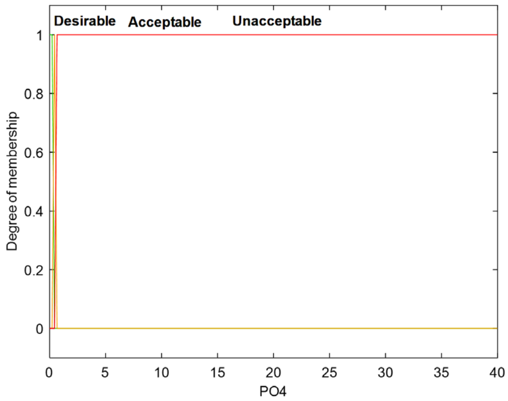
(g)


Desirable Acceptable Unacceptable
Degree of membership
NO3
0
0.2
0.4
0.6
0.8
1
0
10
20
30
40
50
60
70
80

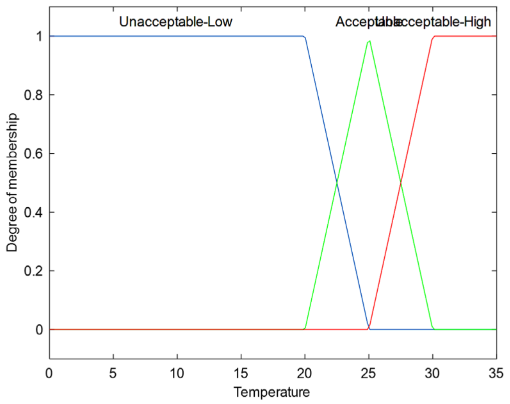
(h)


Desirable
Acceptable
Unacceptable
Degree of membership
SO4
0
0.2
0.4
0.6
0.8
1
0
50
100
150
200
250
300
350

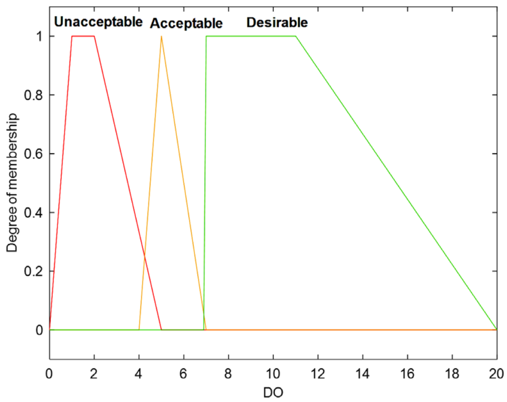
(i)


Desirable
Acceptable
Unacceptable
Degree of membership
PO4
0
0.2
0.4
0.6
0.8
1
0
5
10
15
20
25
30
35
40

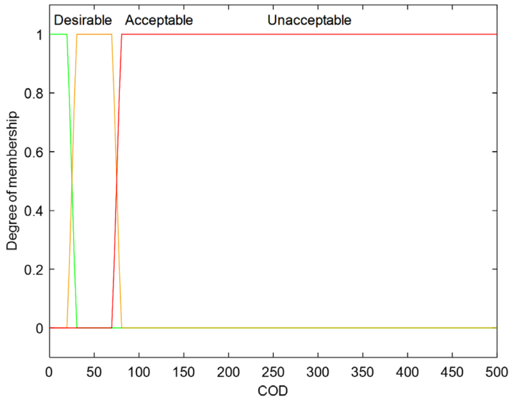
(j)


Unacceptable-Low
Acceptable
Unacceptable-High
Degree of membership
Temperature
0
0.2
0.4
0.6
0.8
1
0
5
10
15
20
25
30
35

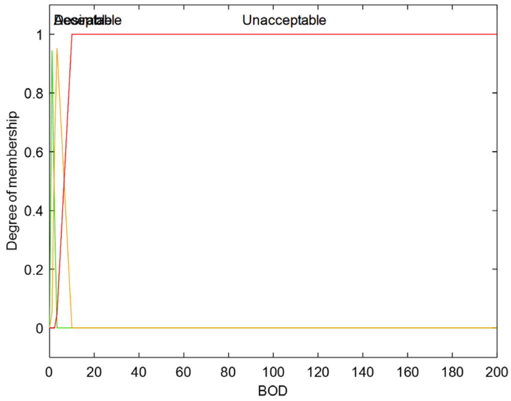
(k)


Unacceptable
Acceptable
Desirable
Degree of membership
DO
0
0.2
0.4
0.6
0.8
1
0
2
4
6
8
10
12
14
16
18
20

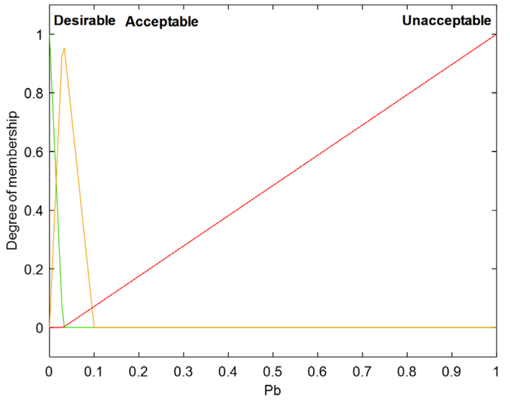
(l)


Desirable
Acceptable
Unacceptable
Degree of membership
COD

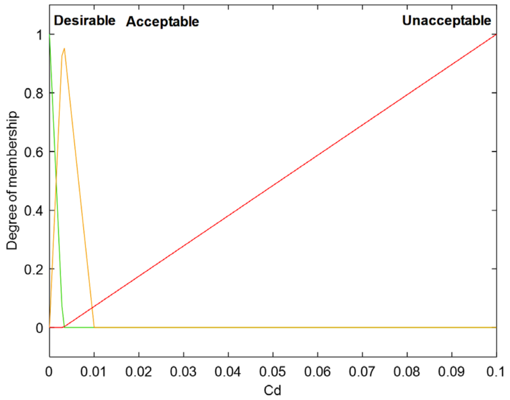
(m)


Unacceptable
Degree of membership
BOD

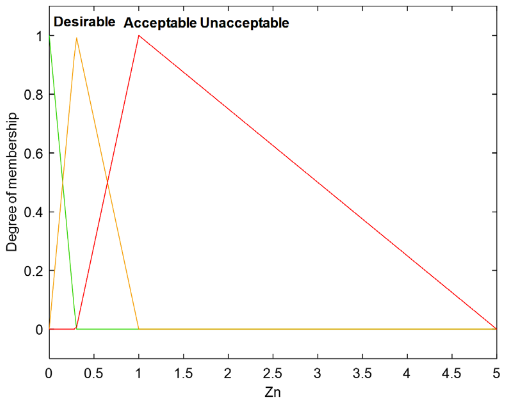
(n)


Desirable
Acceptable
Unacceptable
Degree of membership
Pb

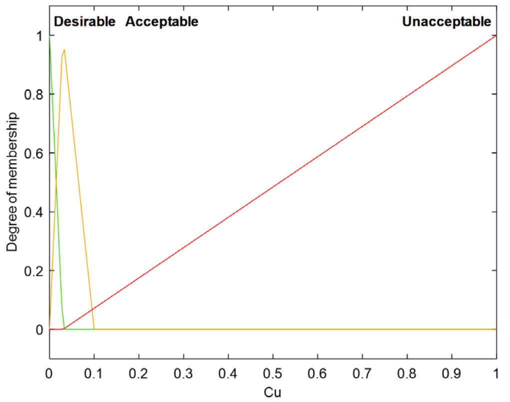
(o)


Desirable
Acceptable
Unacceptable
Degree of membership
Cd

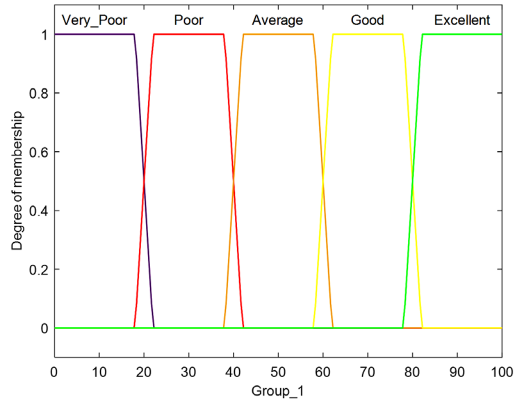
(p)


Desirable
Acceptable
Unacceptable
Degree of membership
Zn

(q)

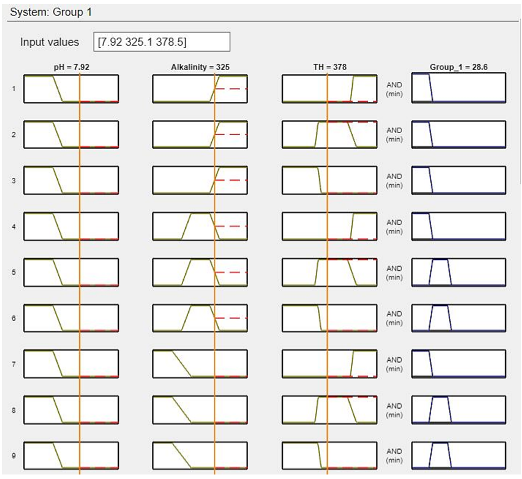

Desirable
Acceptable
Unacceptable
Degree of membership
Cu

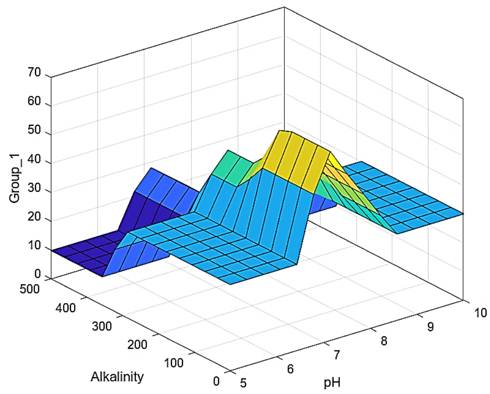
(r)

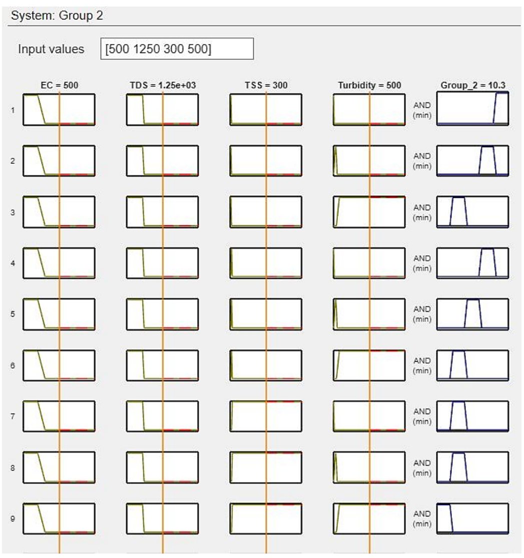


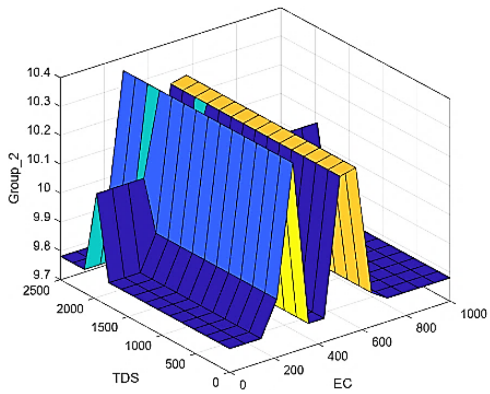
(s)

Figure (3): Fuzzy Set Inputs for the Eighteen Parameters (a to r) and the Fuzzy Output Value (s)**.**









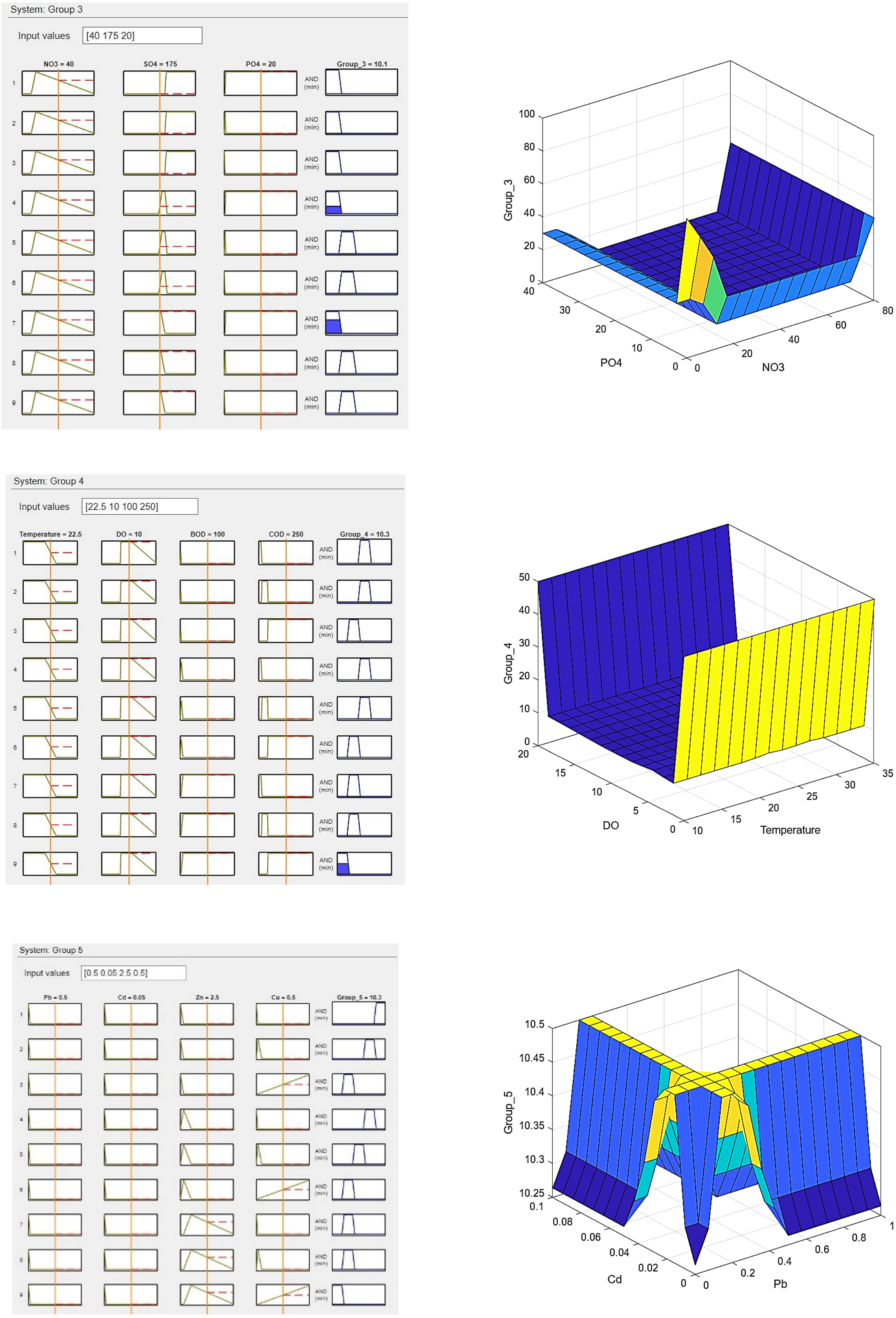


Figure (4): The Inference Rule, and the Control Surface of Group1, Group2, Group3, Group4, and Group5 in the First Layer.

Table (3) The Test Results of Eighteen Parameters from Five Stations.

Water Quality Parameters \ St No.	Wet (13th December, 2024) St1	St2	St3	St4	St5	Dry (26th April, 2025) St1	St2	St3	St4	St5
Temp	14.2	14.6	14.2	14.6	14.7	21	21.1	20.3	20.76	20.71
pH	7.92	7.88	7.73	7.95	7.91	7.76	7.65	7.7	7.84	8.22
Alkalinity	325.1	304.1	288.1	233.2	444	331.4	335.7	300.2	410.2	432.6
TH	378.5	311.1	192.2	261.1	610.2	225	236	310	444	511
EC	880	903	869	778	843	815	865	890	933	911
TDS	572	585	564	507	546	530	543	565	610	591
TSS	112.2	101.2	98	444	211.2	444	342	100	811	251.1
Turb	122.1	111.1	104	510	221	321	111	77	444	66.3
NO_3	45.1	34.4	31.2	50.4	59.2	14.7	17.6	21.1	17.1	25.2
SO_4	115.2	91.2	97.1	95.1	171.1	90	92	87	93	133
PO_4	7.1	5.2	10.1	15.1	27.7	5	5.76	6.05	6.1	9.9
BOD	77.2	62.4	67.2	60.1	111.2	51	71	82	73	91.12
COD	98.1	81.2	87.5	71.1	147.5	77.4	82.3	95.4	82.4	111.2
DO	1.82	1.4	1.67	3.26	2.9	1.9	1.3	1.4	2.1	1
Pb	< 0.006	0.0053	0.03	0.004	0.02	< 0.006	< 0.006	< 0.006	< 0.006	0.01
Cd	< 0.006	< 0.006	< 0.006	< 0.006	0.01	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006
Zn	0.23	0.42	0.44	0.756	1.1	0.1	0.16	0.3	0.72	0.967
Cu	0.07	0.044	0.21	0.29	0.31	0.04	0.043	0.043	0.1	< 0.006

Table (4) Results of FWQI Model.

Stations	Group1	Group2	Group3	Group4	Group5	Station	Classifications
Wet Season							
St1	28.6	10.2	10.2	9.78	46.2	9.78	Very Poor
St2	45.7	10.1	10	9.78	44	9.78	Very Poor
St3	50.5	10	10	9.78	20.5	10.1	Very Poor
St4	45.1	9.78	10.3	10.2	20.5	10.1	Very Poor
St5	15.1	9.78	10.4	10.1	10.5	9.78	Very Poor
Dry Season							
St1	34.4	9.78	11.1	10	48.4	9.78	Very Poor
St2	33.1	9.78	9.81	9.98	48.1	9.78	Very Poor
St3	50.7	10.1	9.85	9.83	48.2	9.78	Very Poor
St4	19	9.78	9.8	9.91	20.5	10.1	Very Poor
St5	13.8	10.1	9.91	9.9	30.6	9.78	Very Poor

Table (5) Classifications of WAWQI ranking [14].

WQI Value	Water Quality
0-25	Excellent
26-50	Good
51-75	Poor
76-100	Very Poor
>100	Unsuitable for reusing purpose

Table (7) Results of Model Validation.

Stations	St1	St2	St3	St4	St5
Wet Season					
WAWQI	158.271046	183.56332	203.80886	263.7766544	422.101687
Classification	Unsuitable for reusing purpose	Unsuitable for reusing purpose	Unsuitable for reusing purpose	Unsuitable for reusing purpose	Unsuitable for reusing purpose
Dry Season					
WAWQI	130.491989	143.08417	167.12177	235.5528751	286.742535
Classification	Unsuitable for reusing purpose	Unsuitable for reusing purpose	Unsuitable for reusing purpose	Unsuitable for reusing purpose	Unsuitable for reusing purpose