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Research Paper

Comparison between fuzzy logic and water quality index (CCME) methods: A case of water quality assessment for livestock watering

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ABSTRACT

This study aimed to evaluate groundwater quality for a group of wells in the area located between Sinjar and Tal Afar districts, west of Nineveh Governorate, to know the most appropriate places to water livestock. Samples were collected from twenty wells distributed throughout the study area and were measured for six months. A fuzzy logic model was developed to integrate eight parameters: pH, Ca, Mg, Na, Cl, PO_4, SO_4, and Fecal coliform (F.Coli). Membership functions for a fuzzy logic model of groundwater quality for livestock watering (GQLW) were constructed using linguistic expressions and trapezoidal shapes. The model was used on a data set of chemical analyses, and biological groundwater samples were taken from the study area. GQLW values ranged from fair to poor. This is due to the high concentrations of most studied parameters, which exceeded the permissible limits for livestock watering in groundwater in the southern part of the study area. The spatial distribution maps of the study area also matched the results of fuzzy Logic, which explains that the best groundwater quality is found in the northern regions. GQLW model evaluation makes this approach a more reliable way to evaluate water quality than traditional methods for assessing groundwater quality data; the correlation coefficient between the acquired data and the CCME quality index had to be estimated. The results of this new indicator showed a respectable correlation (0.76). The GQLW can be a useful tool for decision-making regarding groundwater management in the study area.

1. Introduction

Groundwater is one of the main determinants of Iraq's sustainable livestock development and success. Good management and proper of water resources require knowledge of water quality to address the problems faced by water users, as water is an essential natural resource, especially in areas away from rivers and lakes. Water is necessary for all vital processes, including reproduction, lactation, digestion, regulating body temperature, proper hydration, mineral balance, and waste disposal [1, 2]. If the water quality is poor or limited, the animal's health may be at risk. Cattle are sensitive to the odor and flavor of water, which can affect their water consumption [3]. The amount of dissolved solids present in groundwater can vary depending on several factors, including soil chemistry, amount of rainfall, the aquifer's depth, and the geology's nature [4]. The primary objectives of the study are to assess the variability in groundwater quality across the different wells within the study, to study the chemical composition of the groundwater, and to identify the presence and levels of bacterial contamination in the groundwater between the Tal Afar and Sinjar districts [5]. In general, most groundwater contains different concentrations of dissolved solids, higher than its surface counterpart, because it dissolves many minerals as it passes through the layers of the earth in the different rocky layers. However, despite this, groundwater is characterized by its purity as it is far from direct sources of pollution, and its temperature is often moderate during the different seasons of the year [6]. The study used spatial distribution patterns to identify areas suffering from water pollution; this information can help discover sources of pollution and develop strategies to improve water quality. This information helps protect animals from diseases and helps us clarify and analyze the distribution of different indicators of water quality in specific areas, which contributes to understanding spatial trends and patterns of pollution or groundwater purity [6]. When established, data is collected from various sources such as field and laboratory tests. Geographic Information Systems (GIS) are used to analyze this data and transform it into a detailed spatial image so that areas suffering from water quality problems, such as pollution due to excessive fertilization of agricultural lands or natural obstacles that affect water purity, can be monitored. Determining the temporal and regional trends in groundwater quality is also possible, which helps determine the most effective management and source protection. Artificial intelligence (AI) techniques like Fuzzy logic (FL) methodologies are required to evaluate the water quality index [7]. One area of artificial intelligence methods called FL is thought to be the best for modelling difficult issues [2, 8]. It is imperative to acknowledge that fuzzy logic and fuzzy set theory are instruments utilized to address certain intricate issues in science, engineering, and other specialized fields [9, 10]. However, they also offer a conceptual framework for an entirely new mode of thought [11]. Previous research in this area has focused on assessing the suitability and acceptability of water sources for livestock consumption. The study conducted by Al-Saffawi et al. addressed the quality of groundwater on the left side of Mosul city, focusing on its suitability for watering livestock.

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Nomenclature

CCME	Canadian Council of Ministers of the Environment	FLIS	Fuzzy logic inference system
F_1	Scope	GIS	Geographic Information Systems
F_2	Frequency	NSE	Normalized Sum of Excursions
F_3	Amplitude	$SD\pm$	Standard deviation
FL	Fuzzy logic		

The results of the study indicated that 36% and 55% of the groundwater samples were poor and good, respectively. This deterioration is attributed to the high number of faecal coliform bacteria [12]. The study conducted by Derdour et al. investigated the quantity and quality of water resources in the Wiliaya of Naamea, located in southwest Algeria, with a specific focus on their suitability for livestock watering. The majority of the area was unsuitable for grazing due to limited water resources; only 2.43% of the area was classified as very suitable, 13.42% is somewhat suitable, and 84.15% as marginally suitable for livestock watering. The study highlighted the importance of using spatial distribution analysis to identify the most suitable locations for livestock watering in the region [13]. Kamel et al. studied the quality of water for livestock watering through chemical and biological properties (Cl, TDS, NO_3, SO_4, TPC, and F. Coli) to find out the causes of cow death [14]. The study aims to identify the water characteristics of the area between Sinjar and Tal-afar districts and to evaluate the effectiveness, accuracy, and reliability of the fuzzy logic method in assessing the quality of groundwater allocated for livestock watering, as well as using spatial distribution maps to determine the best places for livestock watering.

2. Experimental section

Groundwater samples from 20 wells were collected for six months. The samples were measured by chemical and biological tests and included pH, calcium, magnesium, and sodium, chloride, phosphate, sulfate, and F. Coli [15–17].

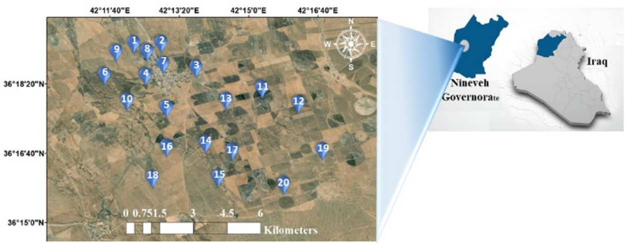


Figure 1. Study area.

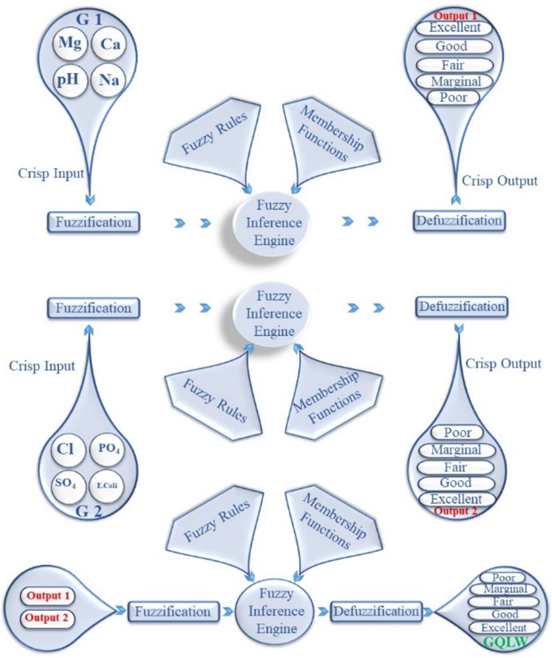


Figure 2. The schematic illustration of the GQLW.

2.1 Description of the area

The study area is located between Tal-Afar and Sinjar districts, west of Nineveh Governorate in Iraq, with a semi-arid climate. Groundwater is the sole source of water supplies required for various purposes. Drilling more wells and using high-capacity pumps to withdraw groundwater at rates exceeding annual recharge amounts has led to an imbalance in the water balance of the aquifer and an increase in the salinity of the groundwater extracted from the area. The depth of the groundwater level ranges between 50-100 meters below ground level, and the productivity of most wells in the study area ranges between 20-50 ($m^3/hour$) [6], Fig. 1.

2.2 Spatial distribution maps

The spatial interpolation method was used to predict and analyze the spatial distribution of the studied parameters (pH, Ca, Mg, Na, Cl, PO_4, SO_4, and F. Coli.) using the kiring method, which is a geostatistical technique and the best procedure for unbiased linear spatial interpolation [18]. The method is asymptotically based and predicts unmeasured values by combining the measured values in a weighted manner [19]. This technique searches for linking well coordinates to the study area using the covariance function and in situ statistical models for the parameters studied [20, 21].

2.3 CCME Model

The Canadian model (CCME), Eq. 6 is applied to the samples measured in the study area, which depends on three main factors: amplitude, frequency, and scope [22, 23]:

1. The F_1 calculation equation (Scope): The scope represents the percentage of variables that fall short of the quality requirement, Eq. 1.

$$F_1 = \frac{Number\ of\ failed\ variables}{Total\ number\ of\ failed\ variables} \times 100 \tag{1}$$

2. The F_2 calculation equation (Frequency): The percentage of samples that meet or surpass quality requirements is called frequency, Eq. 2.

$$F_2 = \frac{Number\ of\ a\ failed\ test}{Total\ number\ of\ failed\ test} \times 100 \tag{2}$$

3. The F_3 equation (Amplitude) is calculated as follows: **A)** Excursion calculation equation, Eq. 3:

$$Excursion = \frac{Failed\ test\ value}{Objective - 1} \tag{3}$$

B) Calculating the Normalized Sum of Excursions (NSE) equation, Eq. 4:

$$NSE = \frac{\sum NSE}{Number\ of\ tests} \tag{4}$$

Thus, the F_3 can be found as, Eq. 5

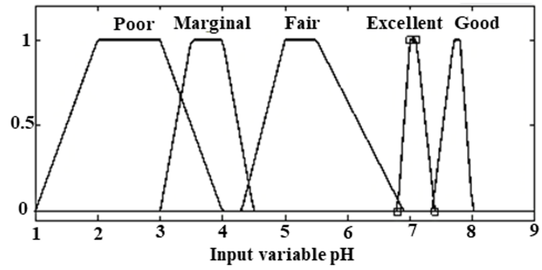
$$F_3 = \frac{NSE}{0.01 \times NSE + 0.01} \times 100 \tag{5}$$

After calculating F_1, F_2, and F_3, the CCME can be calculated using Eq. 6. Furthermore, Table 1 shows the Categorization of the CCME water quality index scale.

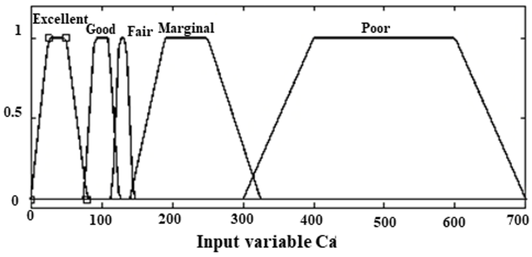
$$CCME = 100 - \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \tag{6}$$

Table 1. Categorization of the water quality indicator scale based on CCME quantity [4].

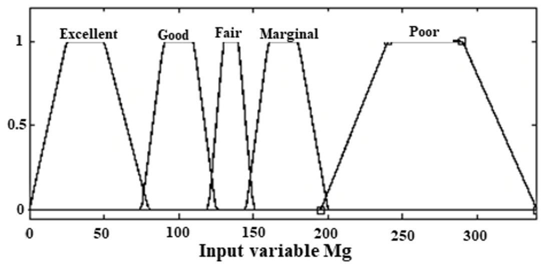
Rating	Poor	Marginal	Fair	Good	Excellent
CCME Values	00– 44	45–59	60–79	80–94	95–100



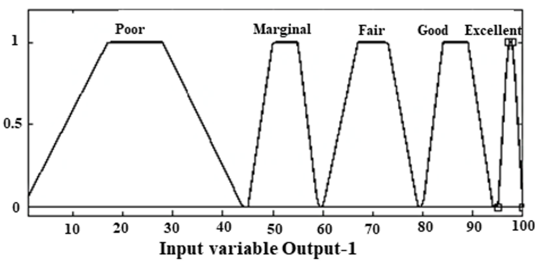
(a) PH



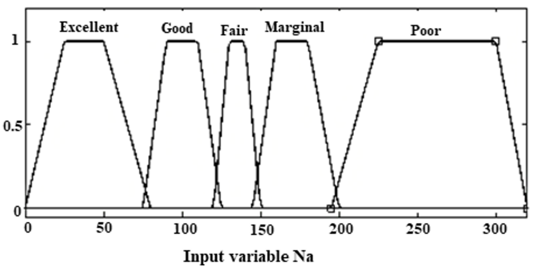
(b) Ca



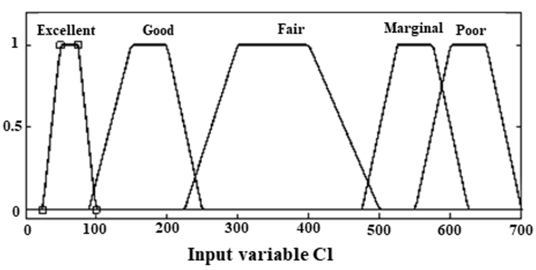
(c) Mg



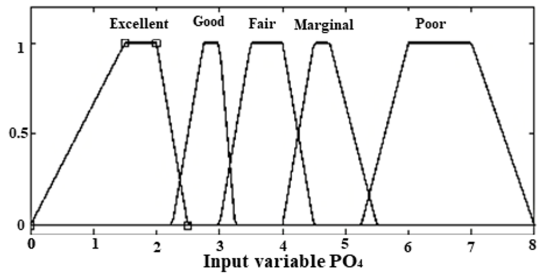
(d) Output-1



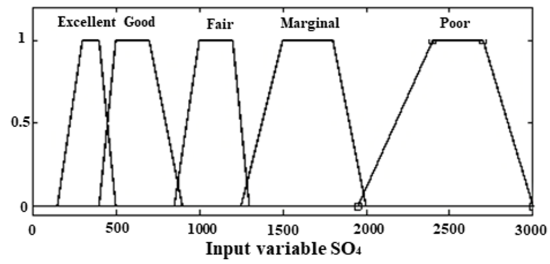
(e) Na



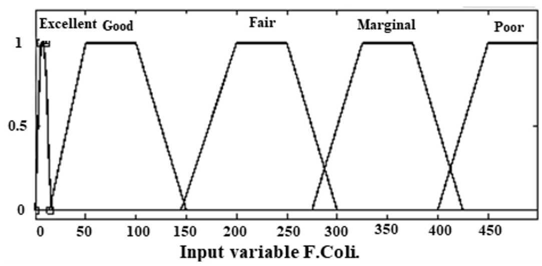
(f) Cl



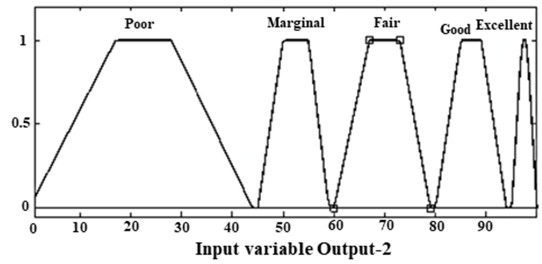
(g) PO_4



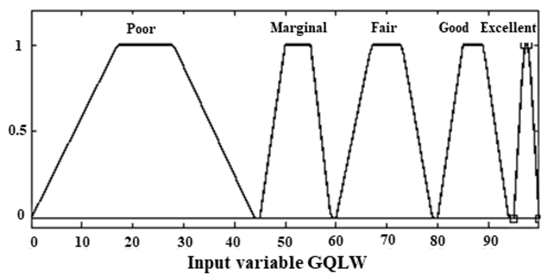
(h) SO_4



(i) F. Coli



(j) Output-2



(k) GQLW

Figure 3. Membership functions of inputs and output.

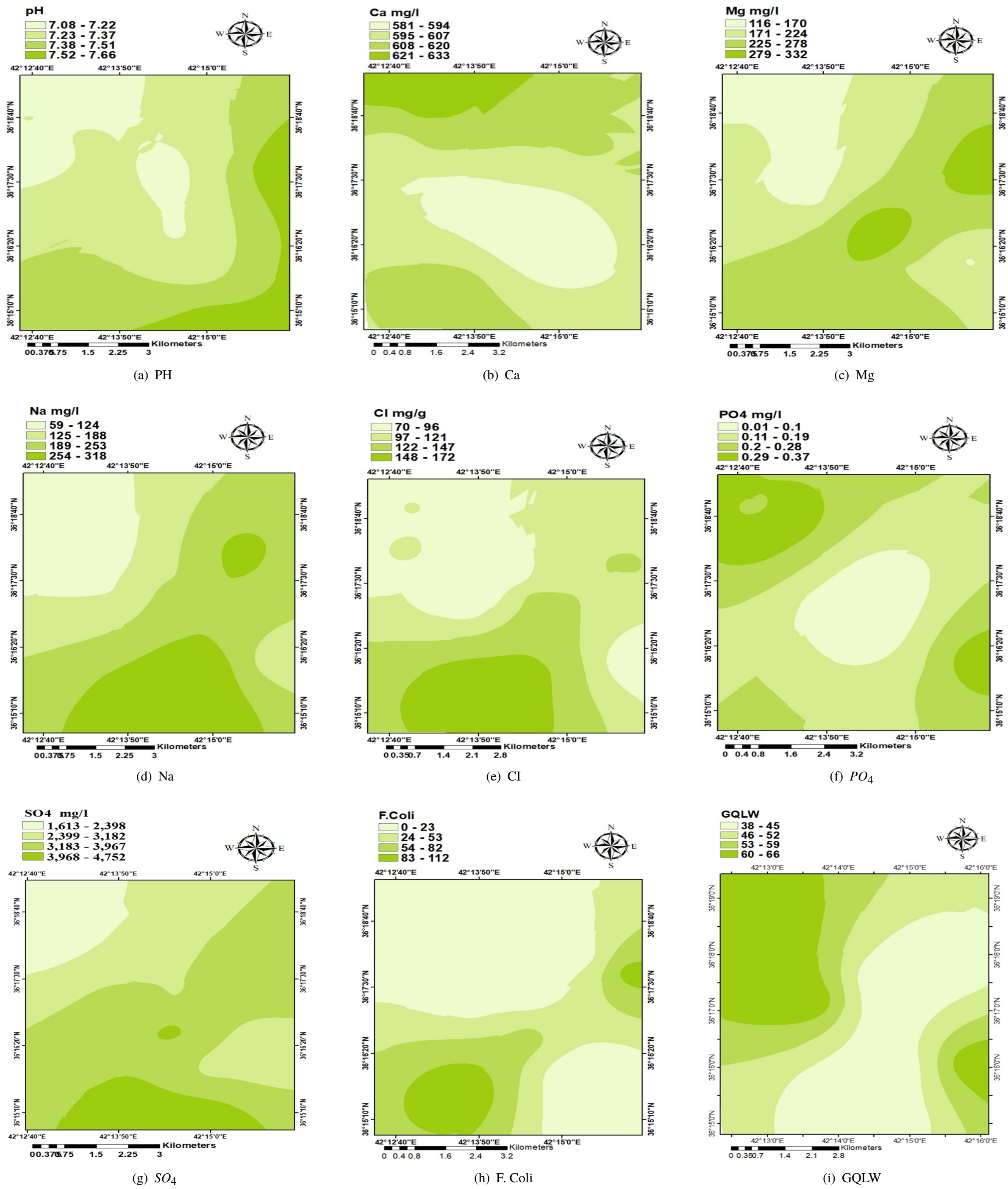
2.4 Fuzzy logic

Using a straightforward foundation built using a common language, fuzzy logic is a versatile technique for creating classification models. To represent groundwater classification and improve the understanding of water quality assessment, especially for general consideration, the water quality index value has been used by computing methods using fuzzy linguistic terms, [9, 24].

Various membership functions might be employed based on the kind of application. The system in this study comprises 220 rules, eight inputs, and three outputs, and is utilized for designing a fuzzy groundwater quality index for groundwater; the output gives the livestock watering quality, which has four sorts and is described by the membership functions planning the linguistic variables [24]. Four linguistic variables were defined, and eight parameters were used as input (pH, Ca, Mg, Na, Cl, PO_4, SO_4, and F. Coli). The output variable is the Fuzzy groundwater quality livestock watering (GQLW) [24,25]. In the current study, each of the parameters was classified into two groups, including the first group (output 1) (pH, Ca, Mg, and Na) and the second group (output 2) (Cl, PO_4, SO_4, and F. Coli). Each parameter consists of four membership functions. To illustrate how the points in each input variable are generated to a membership value ranging from 0-1, membership functions are designed [11,26], Fig. 2. Figure 3 shows the eight membership functions in addition to the output Fuzzy membership functions constructed for all the eight parameters are trapezoidal based on prescribed limits by the World Health Organization [27,28].

3. Results and discussion

The minimum concentration of sodium and chloride in groundwater for use in livestock watering is 50 and 100 (mg/l), respectively, and the maximum is 300.0 (mg/l) for Na and Cl [29], and the percentage of samples within the standard limits for livestock watering was 91% and 100%, respectively. [30].



(a) PH (b) Ca (c) Mg

(d) Na (e) CI (f) PO_4

(g) SO_4 (h) F. Coli (i) GQLW

Figure 4. Shows the spatial distribution of each parameter for the study area as well as the spatial distribution of GQLW.

Table 2. Chemical and F. Coli. results of groundwater (mg/l).

Wells	Values	pH	Ca	Mg	Na	Cl	PO_4	SO_4	F. Coli.
(1)	Min	6.89	504	137	70	84	0.00	1080	0.00
	Max	7.21	688	171	95	94	0.86	2114	2.00
	SD±	0.12	76	13	10	4	0.33	387	0.89
(2)	Min	6.96	544	137	79	106	0.00	1076	0.00
	Max	7.22	664	181	130	146	0.39	3950	0.09
	SD±	0.11	50	17	24	17	0.16	1148	0.04
(3)	Min	7.08	608	107	67	86	0.15	1321	0.00
	Max	7.21	680	142	79	96	0.45	2636	0.03
	SD±	0.06	32	13	4	5	0.13	530	0.01
(4)	Min	6.98	472	176	72	96	0.05	1488	0.00
	Max	7.15	632	224	81	118	0.58	2382	0.07
	SD±	0.06	67	21	4	9	0.19	360	0.03
(5)	Min	7.08	504	127	78	78	0.00	1188	0.00
	Max	7.21	672	185	110	86	0.46	2308	0.04
	SD±	0.05	61	23	13	3	0.20	490	0.02
(6)	Min	7.14	480	112	70	60	0.00	1587	0.00
	Max	7.43	680	198	140	76	0.49	2144	0.20
	SD±	0.12	78	37	28	7	0.20	284	0.09
(7)	Min	7.04	616	100	39	70	0.23	1789	0.00
	Max	7.53	688	176	70	160	0.51	2480	0.04
	SD±	0.20	35	29	12	39	0.11	283	0.02
(8)	Min	7.10	576	83	61	58	0.00	1446	0.00
	Max	7.25	720	161	78	70	0.54	2234	0.00
	SD±	0.07	59	30	7	5	0.22	292	0.00
(9)	Min	7.11	552	112	67	72	0.22	1233	0.00
	Max	7.41	696	166	87	98	0.50	2472	0.04
	SD±	0.12	62	24	8	10	0.13	503	0.02
(10)	Min	7.09	552	137	72	86	0.00	1843	0.00
	Max	7.20	664	195	93	98	0.69	2538	0.07
	SD±	0.04	45	23	9	5	0.27	282	0.03
(11)	Min	7.16	536	110	93	54	0.00	2321	0.00
	Max	7.67	656	197	160	64	0.34	4824	15.00
	SD±	0.19	48	33	25	4	0.15	952	6.66
(12)	Min	7.03	552	110	155	72	0.00	1633	0.00
	Max	7.25	680	245	220	104	0.15	4998	3.00
	SD±	0.11	48	51	26	13	0.07	1209	1.34
(13)	Min	7.04	552	187	235	108	0.00	1941	0.00
	Max	7.41	656	293	275	184	0.08	4270	43.00
	SD±	0.14	41	40	19	33	0.03	839	18.69
(14)	Min	7.10	528	269	230	102	0.00	2557	0.00
	Max	7.36	632	528	265	270	0.15	4968	243.00
	SD±	0.11	42	110	14	72	0.07	940	105.59
(15)	Min	7.22	480	197	205	107	0.00	1921	0.00
	Max	7.29	624	240	455	248	0.79	4178	4.00
	SD±	0.03	58	21	107	58	0.35	842	1.79
(16)	Min	7.27	560	144	155	68	0.00	2629	0.00
	Max	8.20	664	403	370	176	0.56	7389	23.00
	SD±	0.38	41	92	91	44	0.27	1958	10.29
(17)	Min	7.19	584	149	155	134	0.00	2454	0.00
	Max	7.64	680	365	360	216	0.56	6127	460.00
	SD±	0.18	43	78	93	32	0.25	1441	197.96
(18)	Min	7.11	552	96	210	104	0.00	2546	0.00
	Max	7.63	672	365	395	152	0.60	4947	23.00
	SD±	0.19	43	99	71	19	0.27	925	11.17
(19)	Min	7.108	584	206	130	62	0.00	2752	0.00
	Max	8.10	688	451	350	182	0.75	4968	460.00
	SD±	0.36	45	103	83	43	0.33	927	203.96
(20)	Min	7.10	584	139	105	58	0.00	1777	0.00
	Max	7.87	600	197	245	72	1.32	3378	0.00
	SD±	0.28	7	21	55	5	0.55	665	0.00
Standard		6.5-8.5	100-200	50-100	50-300	100-300	2.5-2.5	150-900	0-100

Figure 4 shows the similarity of the spatial distribution of chloride and sodium ions, which indicates that their source is halite rocks. High concentrations of sodium in groundwater lead to dehydration and neurological signs such as blindness, incoordination, convulsions, reclining, and death. The values of pH and phosphate in groundwater ranged between (6.89 – 8.20) and (0.00 – 1.32), respectively. The study concluded that all the groundwater samples analyzed were within the acceptable limits for use in livestock watering and ranged between (6.5- 8.5 and 2.5 mg/l, respectively) [29], the reason for the decrease in phosphate in groundwater is due to its reaction with calcium and the formation of calcium phosphate as a precipitate [31].

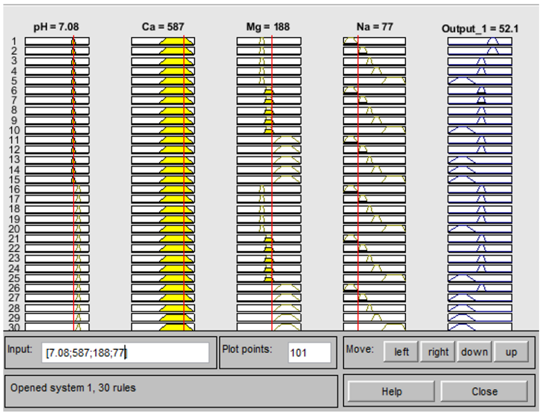


Figure 5. Comparison of GQLW and CCME indices for the different wells of the study area.

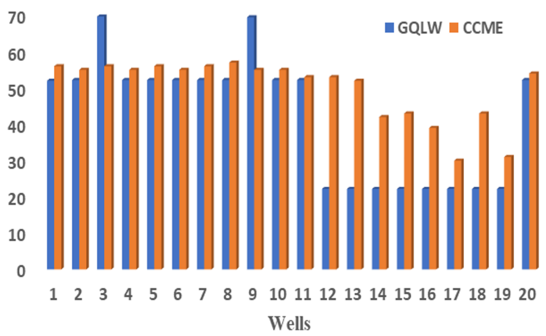


Figure 6. The viewer displays the inputs and the output (1) used in GQLW.

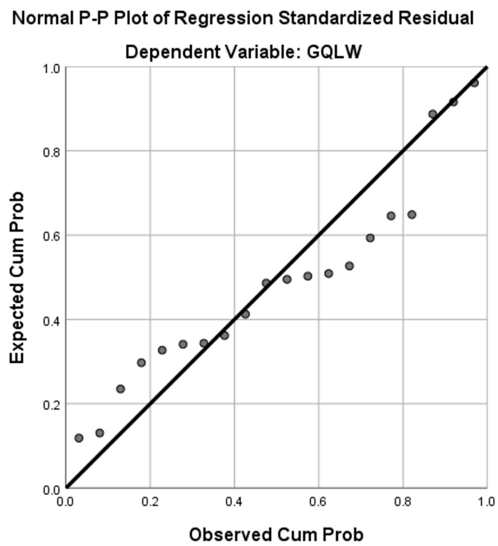


Figure 7. Standard P-P diagram of regression standardized residuals Dependent Variable (GQLW).

The results in Table 2 show that the concentrations of calcium ions reached 720 (mg/l), and the reason for this increase is that the geological layers contain gypsum [32]. High concentrations of calcium lead to functional disturbances in animals [33], while the concentrations of magnesium reached 528 (mg/l) due to the water passing through the pores containing dolomite rocks [34]. Magnesium ions are involved in the composition of essential enzymes, proteins, and amino acids and affect blood pressure in animals, in addition to preventing cancer [12]. The groundwater samples analyzed in the study were found to have the following percentage of values within the permissible limits for livestock watering, 0% and 3% of the calcium and the magnesium values, respectively, This indicates that the majority of the calcium and magnesium concentrations in the studied groundwater did not meet the recommended guidelines for suitability in livestock watering. Figure 4 shows the spatial distribution that the high concentrations of calcium ions in the northwest and southwest, and the lowest concentrations were in the center, unlike the concentrations of magnesium ions, which were high in the center of the study area. The concentrations of sulfate ions varied between (1080 - 4998) (mg/l), and the high levels of certain water quality parameters, such as sulfates, are attributed to the geological composition of the underlying rocks and minerals. As these rock formations dissolve into the groundwater, they contribute to elevated concentrations of these dissolved constituents, which leads to an increase in the concentration of sulfates, as well as agricultural drainage that contains fertilizers and pesticides that contain sulfates. Higher concentrations of sulfate ions in the water used for livestock watering have been shown to lead to a decrease in feed consumption by the animals. In addition to the possibility of sulfates reacting with copper to form copper sulfate, which, when present in the consumed water, leads to an increase in brain disorders [35]. The spatial distribution shows that the highest concentrations of sulfate ions are in the southern part of the study area. As for faecal bacteria, the percentage was 20% within the permissible limits for livestock watering, as faecal bacteria can reach the groundwater due to septic tanks, which can seep into the groundwater of the study area. Table 2 shows the concentrations of the measured standards [36, 37]. The decision on the suitability of groundwater for livestock watering purposes is made by comparing the studied parameters selected in the sample with the standard limits through fuzzy Logic. The fuzzy Logic (output 1) results for the first group showed 85% good and 15% excellent. This is due to the pH and sodium of the groundwater, which were all within the limits of use. For the concentrations of magnesium and calcium, the test results were, to some extent, high in most of the wells. Displays the Matlab rule viewer that is used in FLIS. As an example, the surface graph of the interaction between the pH, Ca, Mg, and Na variables is shown in the following figure, along with the output (1) Fig. 5.
GQLW results for the studied wells showed that 10% were fair, 50% were marginal, and 40% were poor for use in livestock watering. As for the CCME model, 70% were marginal, and 30% were poor Table 3 and Table 4. The proposed model was validated using the relationship between GQLW and CCME Fig. 6, using the correlation coefficient method, and was (0.76). Consequently, the association that was found met the research goal of creating a new index with a more stringent ranking algorithm. Multiple functional regression analysis was used to determine the relationship between the inputs and outputs of the fuzzy logic, and the results showed that the regression analysis is significant through the F value of 13.538 in terms of the sig values of 0.000. The correlation coefficient was strong through the R_1 and R_2 values of 95.3 and 90.8, respectively. Figure 7 shows the normality of Residual to the clustering of points around the straight line. Thus, Residuals follow the normal distribution, which is one of the conditions for the validity of the regression analysis.

Table 3. Results for output 1, output 2 and GQLW.

Well	Output 1	Output 2	GQLW
1	58 Marginal	70 Fair	52 Marginal
2	52 Marginal	52 Marginal	52 Marginal
3	70 Fair	69 Fair	70 Fair
4	52 Marginal	69 Fair	52 Marginal
5	52 Marginal	69 Fair	52 Marginal
6	52 Marginal	69 Fair	52 Marginal
7	70 Fair	52 Marginal	52 Marginal
8	51 Marginal	69 Fair	52 Marginal
9	70 Fair	62 Fair	70 Fair
10	52 Marginal	52 Marginal	52 Marginal
11	52 Marginal	52 Marginal	52 Marginal
12	32 Poor	52 Marginal	22 Poor
13	22 Poor	52 Marginal	22 Poor
14	22 Poor	52 Marginal	22 Poor
15	22 Poor	52 Marginal	22 Poor
16	22 Poor	52 Marginal	22 Poor
17	22 Poor	52 Marginal	22 Poor
18	22 Poor	52 Marginal	22 Poor
19	22 Poor	52 Marginal	22 Poor
20	52 Marginal	52 Marginal	52 Marginal

Table 4. Results for F_1, F_2, F_3 and CCME.

Well	F_1	F_2	F_3	CCME
1	60	37.5	30	56 Marginal
2	60	37.5	33	55 Marginal
3	60	37.5	30	56 Marginal
4	60	37.5	33	55 Marginal
5	60	37.5	31	56 Marginal
6	60	37.5	32	55 Marginal
7	60	35	33	56 Marginal
8	60	32.5	30	57 Marginal
9	60	37.5	32	55 Marginal
10	60	37.5	33	55 Marginal
11	60	37.5	40	53 Marginal
12	60	37.5	41	53 Marginal
13	60	37.5	42	52 Marginal
14	80	40	46	42 Poor
15	80	42.5	41	43 Poor
16	80	47.5	51	39 Poor
17	100	47.5	50	30 Poor
18	80	37.5	45	43 Poor
19	100	42.5	51	31 Poor
20	60	37.5	37	54 Marginal

4. Conclusion

This paper briefly highlights the assessment of groundwater quality for livestock watering purposes using fuzzy logic and spatial distribution for the area between Sinjar and Tal-afar districts. The Groundwater Quality for Livestock Watering (GQLW) approach was found to be a suitable method for assessing groundwater quality for livestock use. This is due to its integrated decision-making process that considers indicators of key water quality parameters. The current study introduced a more dependable and flexible method for evaluating groundwater quality for livestock use compared to traditional approaches. This was achieved by incorporating uncertainties in the measurement and analysis of chemical and biological data during the model development process. According to Fuzzy logic, groundwater quality values ranged between fair and poor. In addition, the spatial distribution showed that groundwater quality for livestock watering is better in the Northwestern regions according to the spatial distribution of the criteria studied. The results of the study revealed a strong positive correlation between the Groundwater Quality for Livestock Watering (GQLW) index and the Canadian Council of Ministers of the Environment (CCME) index, with a correlation coefficient value of 0.76. This indicates a robust direct relationship between the two groundwater quality assessment methods., which means that the indicator GQLW is an effective tool for evaluating groundwater for the purposes of livestock watering.

Authors' contribution

All authors contributed equally to the preparation of this article.

Declaration of competing interest

The authors declare no conflicts of interest.

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Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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