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Assessment of Groundwater Quality in the Semel District of Duhok City, Iraq: Implications for Agriculture and Aquaculture

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ABSTRACT

This study aimed to assess the water quality in the Semel district of Duhok City, Iraq, a key area for agriculture and animal farming. The physical and chemical parameters, including turbidity, pH, electrical conductivity (E.C.), total dissolved solids (T.D.S.), nitrate (NO_3^-), total alkalinity (T. Al), total hardness (TH), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), sodium (Na^+), potassium (K^+), and sulfate (SO^{-4}), were measured in 40 wells, which serve as the primary water source for the region. The results were compared with the World Health Organization (WHO) guidelines to assess compliance and safety. While most physical and chemical parameters were within safe limits, some samples showed elevated levels of NO_3^-, T. Al, and T.H, exceeding the permissible limits for drinking water. The water quality index (WQI) values ranged from 19.8 to 39.59, classifying all samples as "Excellent" or "Good." The findings underscore the importance of continuous monitoring and management to ensure the safety and sustainability of groundwater in the Semel district. Groundwater resources play a crucial role in meeting the region's water demands, particularly for drinking, irrigation, and other domestic uses. However, the increasing reliance on groundwater necessitates regular assessments to evaluate its quantity and quality.

INTRODUCTION

Water is an essential resource that sustains life and supports various ecological and human activities. However, natural processes and human activities often compromise its quality, making the water quality assessment crucial **(Al-Badaii *et al.*, 2013; Tyagi *et al.*, 2013)**. Water quality refers to water's chemical, physical, and biological characteristics, determining its suitability for specific uses such as drinking, agriculture, industry, and recreation. Various factors influence water quality, including the presence of pollutants, temperature, pH levels, dissolved oxygen, turbidity, and the concentration of nutrients like nitrogen and phosphorus. The degradation of water quality can lead to significant health risks, environmental damage, and economic costs **(Singh *et al.*, 2014; Kalagbor *et al.*, 2019)**.

Groundwater is a vital source of fresh water, supplying drinking water to billions of people worldwide and supporting agricultural and industrial activities **(Ishaku, 2011; Sarala & Ravi, 2012)**. Unlike surface water, which is exposed to the atmosphere and more easily contaminated, groundwater is stored in underground aquifers, often making it a more reliable and consistent source **(Adekunle *et al.,* 2007)**. However, groundwater is not immune to contamination **(Ram *et al.,* 2021)**. Pollutants from agricultural runoff, industrial discharges, and improper waste disposal can seep into the soil and reach aquifers, leading to potential health risks and environmental damage **(Ramkumar *et al.,* 2013; Salari *et al.,* 2018; Gani *et al.,* 2024)**. Examining the quality of groundwater is crucial because it ensures the safety of drinking water, prevents the spread of waterborne diseases, and protects ecosystems that rely on this hidden resource **(Kawo & Karuppannan, 2018)**. Regular monitoring and assessment of groundwater quality help detect contamination early, guide the implementation of remediation strategies, and ensure that groundwater remains a sustainable resource for future generations **(Ewaid *et al.,* 2020)**.

To effectively monitor and manage water quality, scientists and environmental agencies utilize the water quality index (WQI). The WQI is a standardized tool that simplifies the complex array of water quality data into a single numerical value, providing an overall assessment of the water body's condition **(Wu *et al.,* 2017)**. This index incorporates multiple parameters, each reflecting a different aspect of water quality, such as the levels of dissolved oxygen, biochemical oxygen demand, pH, nitrates, and total dissolved solids **(Ewaid *et al.,* 2018)**. By assigning weight to these parameters based on their relative importance, the WQI offers a comprehensive evaluation, making it easier to communicate water quality information to policymakers, stakeholders, and the public **(Khaleefa & Kamel, 2021)**. The significance of the WQI lies in its ability to facilitate comparisons between different water bodies or the same water body over time. It serves as a valuable tool for identifying water quality trends, assessing pollution control measures' effectiveness, and prioritizing areas for conservation and remediation efforts **(Kareem *et al.,* 2021)**.

Numerous studies have focused on water quality in Iraq, particularly in rural, village, and agricultural areas. These studies have highlighted the challenges posed by pollution from agricultural runoff, inadequate waste management, and the lack of infrastructure in these regions. Researchers have documented the presence of contaminants such as heavy metals, nitrates, and pathogens in water sources, which pose significant risks to human health and agricultural productivity **(Al-Saffawi *et al.,* 2020; Beg *et al.,* 2021)**. The findings from these studies underscore the urgent need for improved water management practices and infrastructure development to ensure safe and sustainable water resources in Iraq's rural communities.

This study aimed to assess the water quality in the Semel district of Duhok City, Iraq, using the water quality index (WQI) by analyzing a comprehensive set of parameters. By evaluating these factors, the study seeks to provide a detailed assessment of water quality, highlighting any potential contamination and its impact on the suitability of water for various uses. This research is essential for understanding the influence of agricultural and domestic activities on local water resources and for informing future water management strategies in Semel district.

MATERIALS AND METHODS

Study area

Semel is a district located in Duhok City, Iraq, situated approximately 14km (8.7 miles) west of Duhok. It has a population of about 71,557 and encompasses over 20 villages. The geographic coordinates for Semel are 36°51′30″N and 42°51′0.35″E. The elevation in this region ranges between 430 and 450 meters above sea level. The climate in Semel and its surrounding areas is classified as semi-arid, characterized by hot, nearly rainless summers and cold, wet winters. The mean annual temperature is approximately 19.2°C, while the annual precipitation ranges from 450 to 500mm. This climatic pattern is typical of most of the Upper Mesopotamia.

The study area covers approximately 47 square kilometers, including Semel and its villages. This region is crucial for agriculture, providing water for human consumption, irrigation, and animal farming. Around 68% of the area's water needs are met by groundwater, making it vital to investigate the wells and assess their water quality. In this study, 40 wells, which are the primary water sources in this area, have been selected for analysis. In Table (1), the locations of each well, along with their coordinates, are listed and have been geographically distributed using the geographic information system (GIS) technology. The spatial distribution of these wells is visually represented in Fig. (1), illustrating their precise locations within the study area. The GIS analysis helps understand the spatial arrangement and accessibility of these wells, which is crucial for managing water resources in Semel and its surrounding villages.

Table 1. Locations and coordinates of wells

Well	Village	X	Y	Well	Village	X	Y
W1	Bajikandal	273342	4102333	W21	Kawashi	304914	4096065
W2	Semel	276734	4100433	W22	Kirash	299308	4091835
W3	Byezni	276641	4100261	W23	Marina	302419	4087685
W4	Durebon	271864	4107492	W24	Maqabli	302325	4087976
W5	Semel	309243	4081168	W25	Hajia	285724	4091342
W6	Siji	311378	4087684	W26	Kani Arab	287912	4085299
W7	Ashee	302161	4077990	W27	Ismael Aza	303556	4078948
W8	Sheno	278648	4100058	W28	Ismael Afa	290155	4093677
W9	Avzrik	290294	4093607	W29	Bastiki	297611	4092886
W10	Avzrik	315081	4079194	W30	Balqos	297145	4092500
W11	Balqos	296433	4096431	W31	Pawardi	287914	4095615
W12	Dalb	312981	4079329	W32	Kharab	290087	4093547
W13	Dalb	313642	4080300	W33	Karshin	286666	4096580
W14	Rzkar	312281	4072676	W34	Kri Kuri	300130	4081744
W15	Shkefdly	290344	4093378	W35	Kilik	282815	4099439
W16	Qarqari	296000	4096405	W36	Marina	302348	4087493
W17	Yazdin	294293	4089976	W37	Marina	302384	4088280
W18	Kararsh	299314	4091829	W38	Marina	302519	4088086
W19	Karash	315477	4079438	W39	Misirike	40 81 706	38 50 341
W20	Kriban	300542	4079775	W40	Batil	36 39.332	43 54.116

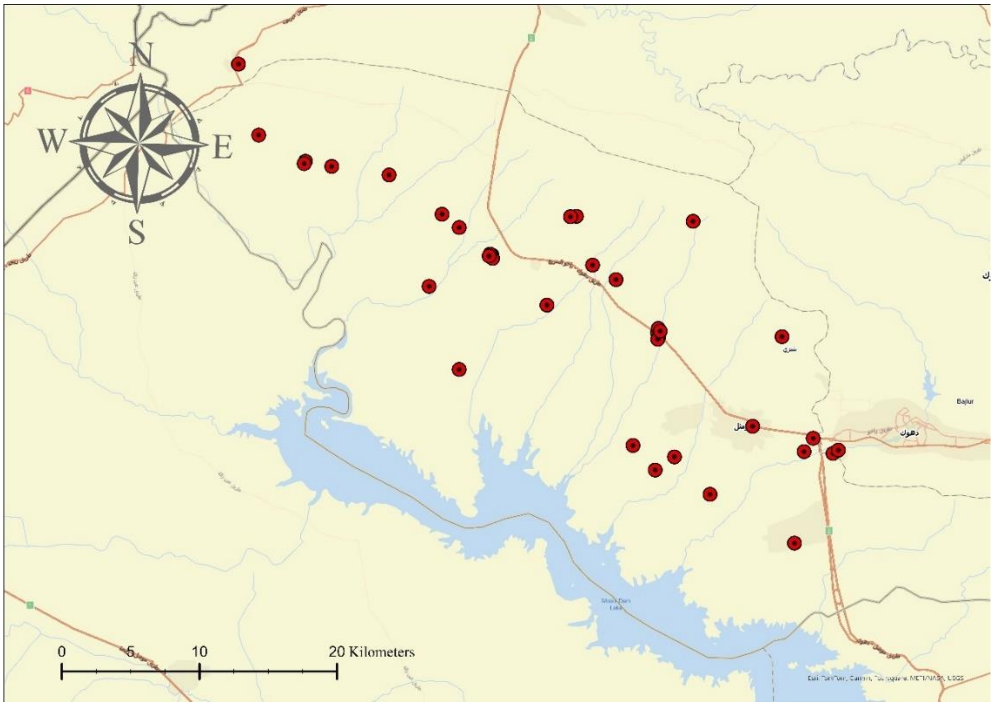

Fig. 1. Geographic distribution of wells in Semel district

Sample collection and experimental preparations

In May 2024, water sampling began at a temperature of 30°C to assess water quality under controlled conditions. To minimize contamination and avoid potential plastic interactions, 250ml glass bottles were carefully selected for sample collection, as higher temperatures can affect the solubility and behavior of various contaminants. Before collecting samples, taps were allowed to run for at least one minute to flush out any accumulated debris and stagnant water. This step was crucial to ensure that the samples accurately represented the well water's quality.

Samples were taken directly from the wells using a sterile sampler to prevent cross-contamination. During sampling, special care was taken to allow thorough flushing of the sampler, ensuring that fresh water from the well entered and exited the sampling device before final extraction **(Aruwa *et al.*, 2017; Smith & Voutchkov, 2017)**. Each sample was immediately sealed to prevent exposure to external contaminants and transported to the laboratory in a temperature-controlled container to maintain sample integrity. Laboratory analyses were conducted within 24 hours of collection to ensure accurate and reliable results. Additionally, field parameters such as pH, electrical conductivity, and temperature were measured on-site using calibrated instruments to provide immediate insights into the water quality and to serve as a reference for laboratory analysis.

The laboratory carried out a detailed analysis to evaluate water quality parameters and chemical composition, ensuring precise measurements in line with established standards. Under controlled conditions, various parameters, including turbidity (Turb.), pH, electrical conductivity (E.C.), total dissolved solids (T.D.S.), nitrate (NO^{-3}), total alkalinity (T. Al), total hardness (TH), calcium (Ca^{+2}), magnesium (Mg^{+2}), chloride (Cl^{-}), sodium (Na^{+}), potassium (K^{+}), and sulfate (SO^{-4}), were carefully assessed.

For each parameter tested, specific methods or devices were employed to ensure accuracy and reliability. The results were then compared to the guideline values set by the WHO to evaluate compliance with safety standards. These permissible limits, detailed in Table (2), act as benchmarks to ensure water quality following the WHO guidelines **(WHO, 2011)**.

Table 2. Water quality parameters, methods, and acceptable limits

Parameter	**Method**	**Allowable limits**	**Unit**
Turb.	Turbidimetric	< 5	NTU
PH	pH meter	6.5 - 8.5	-
E.C	Conductivity	< 400	(µs/cm)
T.D. S	Conductivity	< 1000	(mg/L)
NO^{-3}	UV Sp. Photometric	< 50	(mg/L)
T. Al	H_2SO_4 Titrimetric	< 200	(mg/L)
TH	EDTA Titrimetric	< 300	(mg/L)
Ca^{2+}	EDTA Titrimetric	< 75	(mg/L)
Mg^{2+}	Titration	50-100	(mg/L)
Cl^{-}	Silver Nitrate Titration	< 250	(mg/L)
Na^{+}	Flame Photometric	< 200	(mg/L)
K^{+}	Flame Photometric	< 12	(mg/L)
SO^{-4}	Turbidimetric	< 250	(mg/L)

Water quality index calculation

The water quality index is a critical tool for assessing the overall quality of water bodies, simplifying complex water quality data into a single value that reflects the health of the water. Using the weighted arithmetic index method, the WQI is calculated by assigning weights to various water quality parameters based on their relative importance. These weighted values are then summed to provide an overall index that categorizes the water quality. This method effectively highlights areas where water quality management efforts should be focused.

Water quality is influenced by various ionic, physical, and chemical parameters. Ionic groups like calcium (Ca^{+2}), magnesium (Mg^{+2}), chloride (Cl-), sodium (Na+), potassium (K^{+}), and sulfate (SO^{-4}) play a role in determining the taste, odor, and suitability of water for different uses. Physical parameters, including pH, electrical conductivity (EC), and total dissolved solids (TDS), assess the water's acidity, salinity, and overall dissolved content. Chemical parameters such as nitrate (NO^{-3}), total alkalinity (T. Al), and total hardness (T.H) are crucial in evaluating water's impact on health, ecosystem balance, and infrastructure. Together, these factors provide an understanding of water quality **(Brown *et al.*, 1970)**.

The following method provides an approach to quantifying water quality by considering both the relative importance and the observed deviation of each water quality parameter from its ideal value.

Quality rating (qn) calculation:

qn= (Vn-V0)/(Sn-V0)×100… (1)

Where, Vn is the observed value of the parameter; Sn is the standard permissible value of the parameter, and V0 is the ideal value (usually 0 for most parameters).

Unit weight (Wn) calculation:

The unit weight for each parameter is determined using the equation:

Wn= K/Sn… (2)

Where, K is a proportionality constant, which is calculated as:

K= 1/(Σ 1/Sn)… (3)

Water quality index (WQI) calculation:

WQI= ΣqnWn/Wn… (4)

According to calculations, Table (3) categorizes water quality by aligning WQI values with the guidelines established by the **WHO (2004)**. This classification offers a clear framework for interpreting the WQI results and aids identify the water's suitability for various purposes, such as drinking, irrigation, and industrial use. By adhering to these guidelines, the table helps to pinpoint areas where water quality meets health standards or where it may pose risks, thereby guiding necessary interventions or treatment measures.

Table 3. Water quality classification utilizing the WQI

No.	WQI level	Classification	Purpose of uses
1	0-25	Excellent	Drinking
2	26-50	Good	Drinking and irrigation
3	51-75	Poor	Irrigation and treatment
4	76-100	Very poor	Need attention for irrigation
5	> 100	Unfit	Unfit for all uses

RESULTS AND DISCUSSION

Water quality parameter assessment

The results of the physical and chemical parameters, including pH, electrical conductivity (E.C), total dissolved solids (T.D.S), nitrate (NO^{-3}), total alkalinity (T. Al), total hardness (T.H), calcium (Ca^{+2}), magnesium (Mg^{+2}), chloride (Cl^{-}), sodium (Na^{+}), potassium (K^+), sulfate (SO^{-4}), and turbidity, provide a comprehensive overview of water quality. These results, presented in Table (4), are critical for assessing the water's suitability for various uses and determining any necessary treatment interventions.

Table 4. Results of physical and chemical parameters for water quality assessment

Well	PH	Turb.	E.C	T.D.S	No^{-3}	T. Al	T.H	Ca^{+2}	Mg^{+2}	Cl^-	Na^+	K^+	So-4
W1	7.8	0.5	435	278	9.83	234	224	27	38	10	22.5	1	4
W2	7.69	0.2	451	288	8.55	250	232	29	39	12	22.5	2	4
W3	7.81	0.2	453	290	9.92	256	244	29	42	16	24	1	4
W4	7.22	0.4	1015	650	8.97	234	384	18	60	16	6	2	156
W5	7.66	0.6	971	621	19.31	240	418	90	72	28.8	40	2	46
W6	7.5	0.6	530	339	8.15	242	276	67	26	10	11	1	18.8
W7	7.85	0.4	571	365	29.55	258	292	56	37	22	25.5	1	14
W8	7.46	0.9	773	495	37.42	270	364	64	50	50	25.5	1	22
W9	7.95	0.3	461	295	14.35	220	224	42	29	20	30	2	10
W10	7.77	0.3	527	337	12.8	220	224	37	32	20	51	1	21
W11	7.71	0.2	597	382	16.83	298	328	59	44	20	17.7	1	9
W12	7.34	2.2	1340	857	7.97	234	256	16	87	26	12	2	106
W13	7.46	0.3	877	561	26.62	318	456	102	49	26	19	1	40.8
W14	7.61	0.5	1177	753	32.12	300	356	64	48	68	132.5	2	29
W15	7.79	0.2	437	279	15.06	226	228	34	35	18	29	1	5
W16	7.41	0.8	542	347	16.17	284	288	56	36	14	19	1	9
W17	7.4	0.5	986	631	31.94	126	436	88	77	39.2	36	2	56
W18	7.43	0.4	1005	643	16.04	384	416	106	61	40	19	3	22
W19	7.44	0.3	898	574	47.19	370	416	83	51	28	53	2	30
W20	7.54	0.3	862	552	12.58	208	468	115	44	40	18.3	2	20
W21	7.49	0.4	534	342	13.38	282	332	78	33	12	3.5	0.5	6
W22	7.28	0.4	944	604	25.2	382	448	85	58	24	46	3	4.2
W23	7.55	0.6	830	531	17.7	310	388	82	45	30	45	1	72
W24	7.43	0.3	605	387	20.2	304	332	82	31	24	10.2	2	8
W25	7.77	0.3	492	315	29.55	252	276	59	31	14	9.2	1	4
W26	7.59	0.3	507	324	18.92	250	280	43	42	24	17.8	1	4
W27	7.81	0.2	509	325	14.26	236	228	37	33	20	32.5	1	9
W28	7.87	0.3	543	347	24.45	230	256	48	33	30	35.8	2	10
W29	7.47	0.3	684	438	20.29	326	352	67	45	14	42	1	3
W30	7.46	0.3	617	394	19.71	310	416	66	61	30	16.5	2	8
W31	7.36	0.4	940	602	12.23	356	452	60	74	59	58	2	88.8
W32	7.83	0.6	483	309	12.8	222	224	37	32	16	23	1	9
W33	7.46	0.1	518	331	23.66	248	296	66	32	24	12	1	6
W34	7.45	0.6	1069	684	58.34	232	540	106	67	62	49	1	37
W35	7.91	0.2	471	301	10.94	228	212	29	34	16	31.5	2	10
W36	7.63	0.4	759	485	24.63	322	372	86	38	32	14	2	8
W37	7.49	0.3	569	364	17.72	288	312	72	32	20	10	2	4

W38	7.66	1.8	631	404	8.15	302	336	80	33	26	10.2	1	4
W39	7.12	0.4	1132	725	51.17	344	652	94	102	64	31.5	1	121
W40	7.33	0.1	730	467	21.57	334.8	357.2	70	45	36	47	1	55

Note: All units in mg/L expected PH: has no unit, Turb.: (NTU) and E.C: (µs/cm)

The physical parameters for the 40 selected wells reveal important insights into the overall water quality. The pH levels ranged from 7.12 to 7.95, which falls within the permissible range of 6.5 to 8.5, indicating that all samples are within the acceptable limits for pH and suggesting that the water is generally well-balanced in terms of acidity and alkalinity, making it suitable for most uses. However, the results for electrical conductivity were notably high, ranging from 435 to 1340µS/ cm, exceeding the typical threshold of 400µS/ cm. High electrical conductivity indicates elevated levels of dissolved ions, which could point to potential salinity issues or the presence of other conductive materials. The total dissolved solids in the water samples ranged from 278 to 857mg/ L; the well within the permissible limit of less than 1000mg/ L indicates that the water does not contain excessive amounts of dissolved minerals, making it safe for consumption and other applications. Turbidity, which ranged from 0.1 to 2.2 NTU, also falls within the safe permissible limit of less than 5 NTU, suggesting water is relatively clear, with minimal suspended particles, ensuring its suitability for various uses.

The analysis of chemical parameters for the selected wells shows varying water quality levels, with some wells meeting health and safety standards while others fall short. Nitrate levels ranged from 7.97 to 58.34mg/ L, with the permissible limit being less than 50mg/ L. In this case, 5 wells exceeded the limit, indicating a potential risk of nitrate contamination in those sources. Total alkalinity exhibited a wide range from 126 to 384mg/ L, with 18 wells exceeding the permissible limit of 200mg/ L, representing 45% of the wells. This high percentage suggests that alkalinity is a significant concern in nearly half of the water sources. Total hardness in the samples ranged from 212 to 652mg/ L, with 5 wells exceeding the recommended limit of 300mg/ L, which could indicate potential scaling issues in water systems. Calcium levels ranged from 16 to 115mg/ L, where the permissible limit is 75mg/ L; specifically, wells W4 and W12 exceeded this limit, suggesting localized areas of high calcium concentration.

The levels of magnesium, chloride, sodium, and potassium ranged from 26 to 102mg/ L, 10 to 68mg/ L, 3.5 to 132.5mg/ L, and 0.5 to 3mg/ L, respectively, all of which were within the safe limits. Additionally, potassium and sulfate levels, ranging from 0.5 to 3mg/ L and 3 to 156mg/ L, did not exceed their respective limits of 12mg/ L and 250mg/ L, further indicating that these parameters are within the acceptable levels across all wells. In addition, while some chemical parameters exceeded the permissible limits, others remained within the safe ranges, highlighting specific areas of concern in the water quality.

The analysis of the physical and chemical parameters of the 40 selected wells reveals that while many aspects of the water quality are within the acceptable limits, there are areas of concern. Elevated electrical conductivity, total alkalinity, total hardness, and nitrate levels in several wells suggest potential issues with mineral content and contamination that may require attention. Despite these challenges, most other parameters, such as pH, turbidity, and key ions like magnesium, chloride, sodium, and sulfate, remain within safe ranges, indicating that the water is generally suitable for use, with some exceptions.

Water quality index (WQI)

The results of the WQI calculations, as shown in Table (2) indicate that the WQI values ranged from 19.8 to 39.59. This range places all 40 wells within the "Excellent" and "Good" classifications, meaning they are suitable for both drinking and irrigation purposes. Specifically, 15 wells have a WQI of less than 25, classifying them as "Excellent," while the remaining 25 wells fall between 25 and 50, classifying them as "Good."

Empirical Bayesian kriging (EBK) is a highly effective geostatistical technique used for analyzing and visualizing spatial patterns, especially in the assessment of water quality. This method combines empirical data gathered from multiple sampling sites with advanced statistical models, leading to more precise estimates of water quality variation across different locations. By leveraging this approach, EBK can account for both local data and broader spatial trends, resulting in a refined understanding of water quality distribution.

The spatial distribution map generated by EBK, as shown in Fig. (2), offers valuable insights into the fluctuations of water quality with various geographical factors. These factors include land use practices, proximity to pollution sources, and the area's hydrological characteristics. This type of detailed mapping is crucial for pinpointing regions where water quality may be compromised, enabling the identification of hotspots that require an immediate attention. In addition, the information derived from EBK helps in the development of effective strategies for resource management and informs policy-making aimed at improving water quality. By visualizing areas of concern and providing accurate predictions, EBK aids decision-makers allocate resources efficiently and implemente targeted interventions to address water quality challenges.

The Duhok Governorate heavily depends on groundwater as its main source of water, which is crucial, given the region’s vast agricultural lands and numerous animal farms. Thus, there has been significant research focusing on the quality of water in the area. Our current study is consistent with these previous investigations, as we have observed a similar trend in WQI results.

For instance, **Nazif (2023)** documented WQI values in Duhok Province ranging from 18.47 to 57.9, indicating varying levels of water quality throughout the region. Another study by **Mohammed *et al.* (2024)** reported comparable findings, with WQI values between 20.54 and 36.2 in the Chra region of Duhok, and values ranging from 15.23 to 37.05 in the agricultural areas of Shekhan, also located in Duhok. On the other hand, **Ameen (2019)** found some instances of poor water quality in Barwari Bala; however, these low-quality samples were relatively limited in number. Moreover, **Salim *et al.* (2024)** stressed on the importance of continuous monitoring, particularly in rural parts of Duhok City. Their study highlighted the need for targeted interventions to safeguard access to clean and safe water for these communities. These findings collectively underscore the significance of maintaining high water quality standards and addressing any potential issues that may arise in this groundwater-dependent region.

Table 5. Results of water quality index (WQI) and classification of wells

Well	WQI	Classification	Well	WQI	Classification
W1	26.7	Good	W21	22	Excellent
W2	23.6	Excellent	W22	27.1	Good
W3	24.5	Excellent	W23	28	Good
W4	20.4	Excellent	W24	23.1	Excellent
W5	33.7	Good	W25	26.6	Good
W6	22.8	Excellent	W26	23.2	Excellent
W7	29.4	Good	W27	24.5	Excellent
W8	29.9	Good	W28	29.1	Good
W9	28.7	Good	W29	23.4	Excellent
W10	24.5	Excellent	W30	25.8	Good
W11	25.4	Good	W31	26.6	Good
W12	39.6	Good	W32	27.7	Good
W13	25.9	Good	W33	19.8	Excellent
W14	31.2	Good	W34	32.8	Good
W15	24.1	Excellent	W35	26.9	Good
W16	24.4	Excellent	W36	28.8	Good
W17	29.6	Good	W37	23.4	Excellent
W18	29.8	Good	W38	37.1	Good
W19	28.5	Good	W39	28.7	Good
W20	26.9	Good	W40	20	Excellent

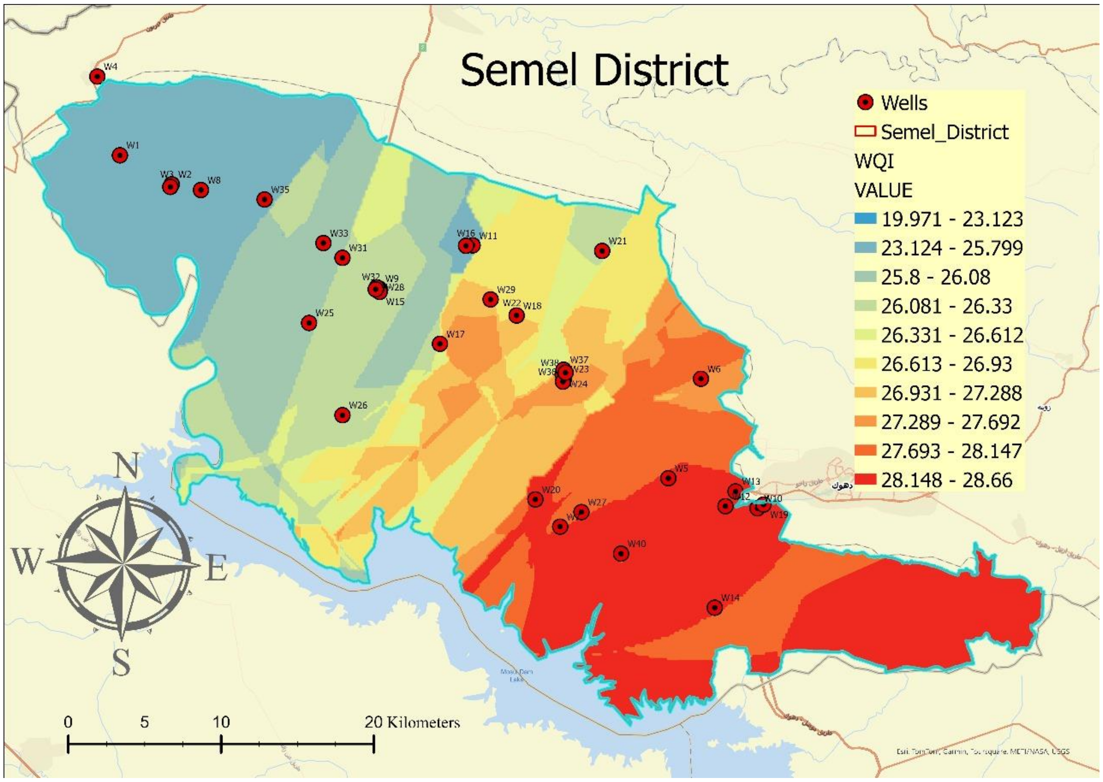

Fig. 2. Spatial distribution of water quality levels

CONCLUSION

The study of water quality in the Semel district of Duhok City, Iraq reveals that the majority of physical and chemical parameters in the 40 wells tested are within the safe limits set by the World Health Organization (WHO). However, specific concerns arise from the elevated levels of nitrate (NO^{-3}), total alkalinity (T. Al), and total hardness (T.H) in some samples, which exceed the permissible limits for drinking water. Despite these issues, the WQI values, ranging from 19.8 to 39.59, indicate that the overall water quality falls within the "Excellent" and "Good" classifications. To ensure the continued safety and sustainability of groundwater in the Semel district, it is recommended that regular and systematic monitoring be conducted, particularly for the parameters that have shown variations above the safe limits. Additionally, implementing targeted water treatment solutions could mitigate the impact of these elevated levels. Public awareness campaigns should also be initiated to educate local communities about the importance of water conservation and proper agricultural practices, which can help reduce the risk of groundwater contamination. Furthermore, collaboration with local authorities to develop a water management plan will be crucial to address current and future water quality challenges in the region.

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