



Assessment of water quality in some wells in Hiznah village, Al-Baha region, Saudi Arabia

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ABSTRACT:

The aim of this study is to assess environmental parameters and heavy metals in some randomly wells in Hiznah village, Al-Baha region, Saudi Arabia. TDS and conductivity were examined using ultrameter 6PII. Heavy metals were detected using the Inductively Coupled Plasma technique by optical emission spectroscopy (ICP-OES). The pH was observed using pH meter. The NO₃ and Fe were detected using Hash DR 900 multiparameter portable colorimeter. Titration system was employed to reveal Cl⁻ and total hardness. Loads of Total bacterial count (TBC), total coliform bacteria (TCB), and total *Escherichia coli* (*E. coli*) were screened using the IDEXX Colilert method. The SPSS package, version 20 (IBM) was applied to statistically analyze all data. Results revealed that temperature (19.80 ± 0.75), TDS (671.94 ± 212.38) except sample 9, pH (7.95 ± 0.29), Fe (0.06 ± 0.03) and NO₃ (10.53 ± 1.11) were within permissible limits of WHO standards for drinking water. Also, five heavy metals Cu, Pb, Hg, Mn and Cd were below limits of WHO standards for drinking water, while two of them Zn (0.098 ± 0.182) and Al (0.012 ± 0.021) were within WHO acceptable limits. Conductivity (1343.89 ± 424.77), Chloride (220.57 ± 49.25), total hardness as CaCO₃ (530.39 ± 112.44) acceded the WHO permissible limits in (eighteen, five, and nine well samples, respectively). There was no contamination with *Escherichia coli* which represented zero in all samples. Also, concentrations of TBC (22.22 ± 2.16) were very low in all wells. However, all water samples were contaminated with TCB (11.89 ± 4.47). Contamination of wells with TBC, conductivity, chloride and total hardness may attributed to both anthropogenic and agricultural sources. This research recommended that wells in hiznah village should be monitored and treated before use. Further research is required for the screen of other intestine bacteria that could effect health.

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Introduction

The quality of drinking water is very important for human health, as many diseases are transmitted through contaminated water, such as cholera, hepatitis A, typhoid, diarrhea, dysentery (Talpur *et al.*, 2024). Also, contamination of drinking water with chemical elements such as nitrates, fluoride, arsenic, lead, and cadmium poses a serious health risk to humans if not properly monitored (Jurczynski *et al.*, 2024). Chemical and microbial pollutants seep into drinking water sources through incomplete conventional treatment and surface runoff, potentially posing a risk to public health when consuming this water and underscoring the importance of monitoring its quality (Mazhandu & Mashifana, 2024). Moreover, Diseases such as high blood pressure, cardiovascular problems, and kidney disease are linked to the consumption of highly saline drinking water (Costopoulos *et al.*, 2025).

The main source of drinking water worldwide is groundwater, especially in rural areas. Therefore, the quality of this water is studied by scientific agencies to determine the type and quantity of natural and human pollutants that are related to potential health risks (Al Mamun *et al.*, 2025). Nitrates are an example of chemical pollutants in well water, resulting from agricultural runoff and natural geochemical processes. Numerous studies indicate the frequent presence of nitrates in well water, often exceeding permissible limits. Children are particularly vulnerable to the health risks associated with consuming water containing high levels of nitrates (Abba *et al.*, 2023). Heavy metals such as lead, nickel, copper, cadmium, zinc, and others leach into groundwater from various sources, either naturally through rock weathering processes or through agricultural runoff, industrial wastewater, and sewage resulting from human activity. Therefore, exceeding permissible concentrations of these metals poses chronic health risks to humans (Nezar H. M. Khedary, 2014). On the other hand, microbial contamination of well water is another important aspect of assessing its quality. *Escherichia coli* and fecal coliform bacteria are among the pathogens that can reach well water through flooding, posing a health risk if this water is consumed. This poses a health risk if the water is consumed without prior testing and treatment to ensure its safety (Pieper *et al.*, 2021).

The aim of this research is to determine physicochemical parameters including some heavy metals, and bacterial loads in some wells in Hiznah village, Baljurashi city, Al-Baha region, Saudi Arabia. Also, to compare these parameters with world health organization (WHO) standards for drinking water quality. Moreover, to find out relationship between these environmental variables themselves in one hand, and between them with spatial variation on the others.

Materials and Methods

The study site sample collection

Eighteen wells were randomly selected from different areas in Hiznah village and during summer 2025, (Figure 1) and (Table 1). These individual sites of wells were grouped to 3 different zones based on geographical locations (Figure 1) and (Table 2).

Following our previous well-documented research (Albaggar, 2020), water samples were collected from 18 randomly selected wells in Hiznah village. According to previously published methods (Albaggar, 2020, 2021; APHA, 2012, 2023; Behailu *et al.*, 2018), water samples were collected from 18 wells during 2025 using sterile 100 mL bottles for bacterial examination, and polyethylene bottles for physicochemical tests. Each sample was labeled and transported and stored at 4 °C until analysis in the laboratory of the Biological departments in the faculty of science in Aqiq. Al-Baha University. All samples were transported again to Gulf Star Laboratory in Qatif, Saudi Arabia by Samsa company for further environmental parameter analysis.

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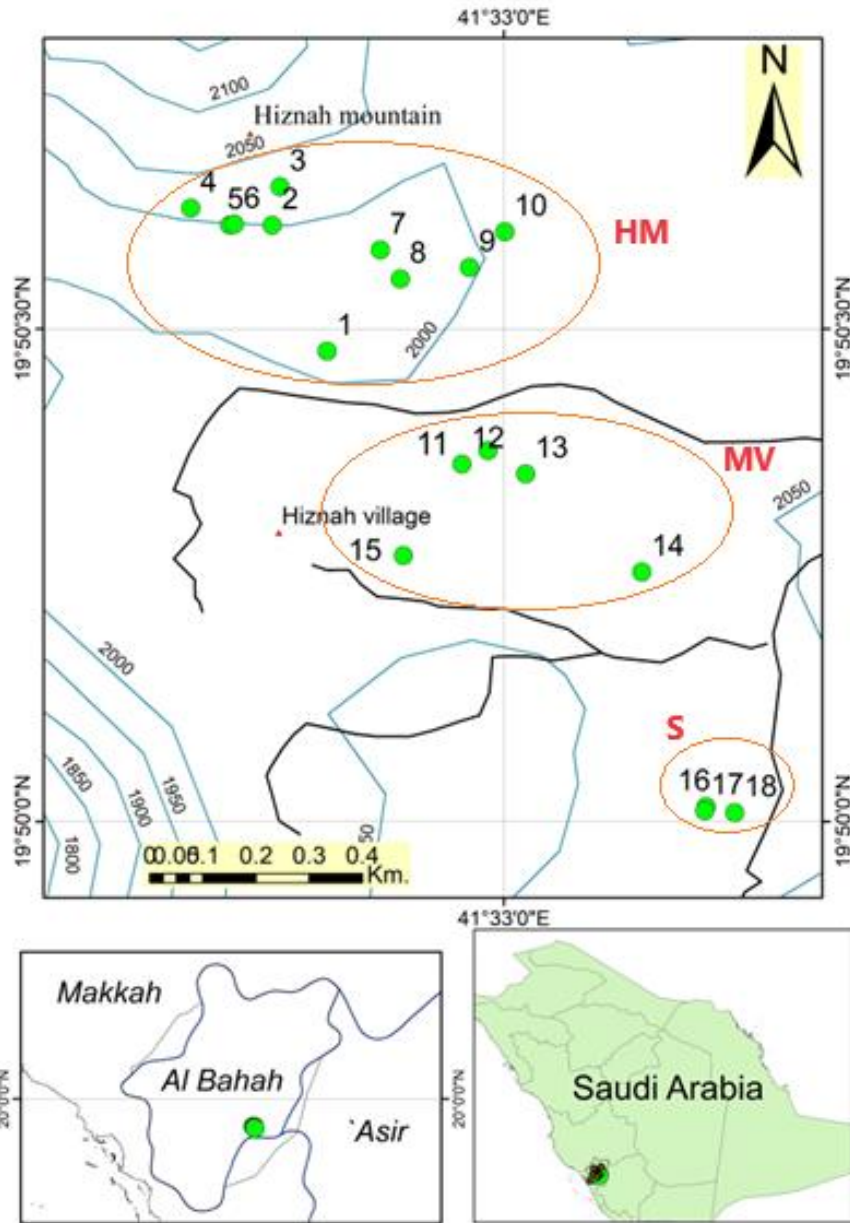


Figure 1. Geographical location of targeted wells (n=18) in eighteen sites in Hiznah village (Al-Baha region, Saudi Arabia).

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Table 1. Numbers, names and locations of targeted wells in Hiznah village (Al-Baha region, Saudi Arabia).

Well no.	Names of wells (location)	coordination	
		Latitude	Longitude
1	Tarefah	19.8412929	41.5470066
2	Aljanab	19.8434213	41.5460769
3	Albaremeen	19.8440754	41.5462127
4	Albannan	19.8437121	41.5446996
5	Alsaada	19.8434245	41.5453584
6	Alwadi	19.8434415	41.5454365
7	Almahrorah	19.8425162	41.5482454
8	Alquraa	19.843005	41.5479088
9	Fahmah	19.8427083	41.5494182
10	Altawelah	19.8433144	41.550013
11	Joaranah	19.8396107	41.5497314
12	Almadra	19.839383	41.5492892
13	Beer Raqeeb Albeer	19.8392177	41.5503679
14	Aljammah	19.8375582	41.5523341
15	Makhool Alsofla	19.8378344	41.5482994
16	Juran	19.8335881	41.5534211
17	Alkharebah	19.8335219	41.5534
18	Alhasan	19.8334856	41.5539049

Table 2. Sites as groups in Hiznah village region, (Al-Baha region, Saudi Arabia).

Group number	wells no.	Group name	Symbol
1	1,2,3,4,5,6,7,8,9,10	Hiznah Mountain	HM
2	11,12,13,14,15	Middle of Village	MV
3	16,17,18	Shaaf	S

HM: Hiznah mountain, MV: middle of village, S: shaaf

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Physical, chemical, and bacterial analyses

Physical, chemical, and biological parameters of well water samples were assessed according to (APHA, 2023).

Analysis of physical parameters:

Techniques include the ASTM mercury thermometer (Gilson company) to measure water temperature. Also, TDS ultrameter 6PII (Myron L company), and the method was (APHA 2540C) for total dissolved solid (TDS) and electrical conductivity.

Analysis of chemical parameters:

Heavy metals (Cu, Pb, Hg, Mn, Zn, Al, and Cd) were analyzed using the Inductively Coupled Plasma technique by optical emission spectroscopy (ICP-OES), and methods were (USEPA 6010 D). Concentration rang of heavy metals from $\mu\text{g/L}$ to g/L can be determined by ICP-OES. It also detects lower limits of elements in short time compared with other methods, and it also neglects the interference of chemicals (Khan *et al.*, 2022). pH was tested using pH meter (BAOSHISHAN company, model TL-40, 2017), and the method for measuring pH was (APHA 4500 – H + B, electrometric method). Nitrate and Iron were measured using Hash DR 900 multiparameter portable colorimeter, and methods for measuring them were (APHA 4500-NO₃- F, and APHA 3120, respectively). Titration system was used to detect chloride and total hardness in two different ways. Chloride was titrating with silver nitrate AgNO₃ (concentration: 0.02 N), while total hardness was titrating with EDTA solution (concentration: 0.02 N).

Analysis of biological parameters:

Total bacterial count (MPN /100ml) , total coliform bacteria CFU/ml), and *Escherichia coli* (MPN/100 ml) were screened using the IDEXX Colilert method (Palacios Delgado *et al.*, 2025).

Statistical analysis

All data were statistically analyzed using SPSS package, version 20 (IBM). To check for the normality of data distribution, Kolmogorov-Smirnov test was applied. Then, all data that appeared not normal for their distribution were transformed into square root. Significant differences for all data between sites were examined using One-way ANOVA. After that, Post hoc comparisons were applied using Dunnett's T3 test to check for individual differences between wells as groups. The relationships between environmental data were examined using Spearman's rank correlations (*rs*) (Field, 2018).

Results and discussion

Water quality standards vary depending on the intended use (drinking, industry, agriculture, etc.). International standards used to determine water quality include temperature, pH, total dissolved solids, electrical conductivity, turbidity, nitrates, phosphates, dissolved oxygen, water hardness (calcium and magnesium), and, most importantly, the detection of heavy metals and pathogenic microorganisms (Chidiac *et al.*, 2023). It is crucial to compare these parameters with (WHO) standards to ensure water safety and prevent waterborne diseases. Periodic water testing reveals the quantity and type of contaminants present, while comparing these parameters to WHO and international standards demonstrates compliance with safety guidelines (Zainurin *et al.*, 2022). In this research, we focused on the most important standards for the quality and safety of drinking water and then compared them with the standards of the WHO.

Three physical parameters (temperature, TDS and conductivity), five chemical parameters (pH, Cl⁻, CaCO₃, Fe, NO₃), seven heavy metals (Cu, Pb, Hg, Mn, Zn, Al, Cd), and three bacterial parameters (total coliform bacteria (TCB), Total *Escherichia coli* (T E.coli), total bacterial count (TBC)) are presented in Table 3 A. and Table 3 B.

The water temperature ranged from 18 to 21 degrees Celsius, and the mean variance was (19.80 ± 0.75). It is important to maintain the temperature of drinking water between 20-25 degrees Celsius (Wei *et al.*, 2021) .Water temperature affects biological activity and chemical reactions. In warmer water, for example, the level of dissolved oxygen decreases, the metabolic rate of aquatic organisms increases, pathogens proliferate, and the amount of toxic compounds rises (Khaliq *et al.*, 2024). Another critical parameter is pH which is considered an indicator of acidity or alkalinity of well water. The pH values ranged from 7.40 to 8.40 and were within permissible limits recommended by WHO for drinking water standards. The ideal pH for well water used for drinking ranges between (6.5 – 8.5). Any increase or decrease in pH from these values affects the health and safety of water networks and consumers. For example, acidic water (pH below 6.5) can cause corrosion of water pipes and leakage of toxic metals like lead, while alkaline water (pH above 8.5) can reduce the effectiveness of water purification and cause the water to become bitter (Arhin *et al.*, 2023).

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The close relationship between electrical conductivity and total dissolved solids (TDS) has been revealed by numerous scientific studies. Conductivity describes the ability of water to conduct electricity based on the concentration of ions present in the water. These ions are part of the total dissolved solids (TDS), and therefore, the higher the concentration of TDS in the water, the higher the conductivity (van Niekerk *et al.*, 2014; Verma, 2025). However, the different composition of water and the level of salts affect the relationship of conductivity to total dissolved solids in water, and therefore this requires the use of calibration equations, as many researchers have pointed out (Lucas Rego Barros *et al.*, 2020). The TDS values ranged from 246 mg/L (sample 14) to 1015 mg/L (sample 9). The mean variance values of TDS were (671.94 ± 212.38) . All TDS samples were within acceptable limits recommended by WHO (500-1000 mg/L) except sample 9 (1017 mg/L), and this may be because of agricultural runoff which contains mainly organic matter, salts and minerals that have been dissolved in water (Weber-Scannell & Duffy, 2007).

Conductivity testing as an indicator for drinking water quality reflects the concentration of dissolved salts and minerals. There is no strict health-based limit for conductivity, however, WHO set reference value of conductivity less than or equal to 250 $\mu\text{S}/\text{cm}$ for quality of drinking water (WHO, 2017). On the other hand, many water-related organizations have set limits for water conductivity values. For example, the conductivity of good drinking water ranges from 250 to 750 $\mu\text{S}/\text{cm}$ (Fentie *et al.*, 2024). In this investigation, well water samples had conductivity ranging from 492 $\mu\text{S}/\text{cm}$ (sample 14) to 2030 $\mu\text{S}/\text{cm}$ (sample 9). The mean variance of conductivity was (1343.89 ± 424.77) . All conductivity values in well water samples exceeded the reference value by WHO (250 $\mu\text{S}/\text{cm}$). An increase in dissolved ions in well water, such as chloride, nitrate, sodium, calcium, and magnesium, increases conductivity values (Mathur, 2014). The conductivity values in wells are affected by the mineral composition of the surrounding rocks and soil (Temagee *et al.*, 2025), and also by ions such as nitrate, potassium, and phosphate come from agricultural activities through the use of fertilizers and pesticides (Al-Sulttani *et al.*, 2024).

Concentration of chloride ranged from 122 mg/L (sample 18) to 311.96 mg/L (sample 9). The mean value of chloride was $(220.57 \pm 49.25 \text{ SD})$. Five well water samples (2, 3, 8, 9 and 13) exceeded permissible limits recommended by WHO (250 mg/L). Chloride in well waters originates from natural geological processes through dissolution of minerals like halite and sylvite (Saad *et al.*, 2023), agricultural activities through application of fertilizers and irrigation processes (O'Leary *et al.*, 2015), and also human activities (Hong *et al.*, 2023).

Total hardness ranged from 366 mg/L (sample 13) to 784 mg/L (sample 9). Total hardness levels were above WHO limits for drinking water in half water samples (wells: 3, 5, 6, 7, 8, 9, 9, 11, 12 and 16). The mean total hardness value $(530.39 \pm 112.44 \text{ SD})$. Dissolved cations in well water, particularly calcium and magnesium, is the reason for water hardness. These cations are produced naturally from the dissolution of carbonate minerals such as limestone as groundwater moves through soil and rock (Gebresilasie *et al.*, 2021). Also, calcium and magnesium in wells can be increased by human and agriculture activities such as the application of fertilizers, irrigation and industrial discharges (Wen *et al.*, 2024).

The Fe concentration ranged from 0.02 mg/L (samples 7,8 and 17) to 0.12 mg/L (sample 11). The mean value of Fe was perceived $(0.06 \pm 0.03 \text{ SD})$. The concentrations of Fe were within allowable limits of 0.3 mg/L in drinking water (WHO, 2017). The reference value (0.3 mg/L) reflects the aesthetic aspect in order to prevent problems with the taste and color of the water and does not necessarily reflect toxicity and health effects (WHO, 2022). The Earth's crust is very rich in iron, and the dissolution of iron-bearing minerals (such as iron sulfate and iron oxides) found in soil and rocks by rainwater is one of the important natural sources of iron in well water (Hossain *et al.*, 2015). In addition, anthropogenic and agricultural activities can contribute to elevated Fe concentrations in well waters (Mamadou *et al.*, 2021).

The NO_3 concentration ranged from 8.70 mg/L (sample 1) all the way up to 12.70 mg/L (sample 14). The mean NO_3 value was $(10.53 \pm 1.11 \text{ SD})$, and it was within WHO permissible limits. One of the most common pollutants in wells water is NO_3 . Nitrogen-bearing materials such as organic matters, animal waste and fertilizers can be dissolved and launched their contents of NO_3 which in turn leach through soil layers into wells water (Alharbi & El-Sorogy, 2023). Infants are more susceptible to health risks from increased nitrate levels in drinking water. Symptoms of blue baby syndrome, also known as Methemoglobinemia, are one example (Sadeq *et al.*, 2008).

The heavy metals studied in this research can be divided into essential metals (Cu, Zn, and Mn), if they are presented in water in small concentrations, and non-essential and toxic metals even at low concentrations (Cd, Hg, Al, and Pb). Heavy metals can accumulate in well water, thus posing an environmental and health risk. In addition, the danger lies in the ability of them to bioaccumulate within the organs of living organisms through the food chain, and then their ability to biomagnify and transform into more toxic substances over time (Almashhadany *et al.*, 2024; Hejna *et al.*, 2018).

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Heavy metals (Cu, Pb, Hg, Mn, Zn, Al, and Cd) share the same primary sources of contamination in well water. For example, human and agricultural activities (mining, industrial waste, and the use of fertilizers and pesticides) lead to these metals seeping into well water through surface runoff, thus increasing their concentrations. Additionally, natural weathering of rocks and soil is another source of aluminum, manganese, and copper contamination in well water (Fu *et al.*, 2023; Islam *et al.*, 2025; Obaje Daniel, 2023).

The mean variances of five of heavy metals Cu, Pb, Hg, Mn and Cd (0.003 ± 0.000 , 0.008 ± 0.000 , 0.0006 ± 0.000 , 0.001 ± 0.000 and 0.008 ± 0.000 , respectively) in all samples, and also Al in most wells (samples 1,2,3,5,6,7,8,9,10,12, and 16) in the table 3A. and 3B., indicate that they presented in well samples in very small concentrations, and therefore the ICP-OES device cannot measure them, because they are below its detection limits, usually below the above mean values in ppm levels (parts per million) equivalent to mg/L. However, device like Inductively Coupled Plasma Mass Spectrometry (ICP-MS) can detect lower concentrations, usually ppt (Parts-per Trillion) and also ppq (Parts-per Quadrillion) levels (Yang *et al.*, 2021). On the other hand, Zn in all samples and Al (samples 4,11,13,14,15,17 and 18) were the only concentrations detected by ICP-OES device, with mean values of ($.098 \pm .182$ SD, and $.012 \pm .021$ SD, respectively). Zn ranged from .014 mg/L (sample 14) to .680 mg/L (sample 11), while Al ranged from .001 mg/L all the way up to .071 mg/L in concentration (sample 13).

Total coliform bacteria (TCB) values ranged from 8 MPN/100 mL (in 44.44% of total samples) to 20 MPN/100 mL (sample 6), with mean value of (11.89 ± 4.47 SD). This indicated that all well samples were contaminated with TCB above permissible limits recommended by WHO standards for drinking water. TCB are an important indicator for identifying potential contamination pathways and assessing water quality. Their presence in well water suggests the presence of contaminated surface water, poor well construction, or inefficient nearby wastewater treatment facilities (Morris *et al.*, 2022). Murray *et al.* (2018), evaluated private wells in Maryland, USA and found that approximately 25% of these wells were contaminated with TCB, with emphasizing the important use of TOB test as important indicator for potential pathways of wells contamination.

All well samples, on the other hand, were not contaminated with total *Escherichia coli* (T E. coli). Total *E. coli* concentrations were not detected in any 100 mL, with mean value of (0.00 ± 0.000 SD). T E. coli must be zero in 100 mL of drinking water as recommended by WHO standards. The presence of T *E. coli* in wells is an indicator of fecal contamination that comes from animal and human wastes. They are indicators of the presence of pathogens in wells compared with the presence of total coliform bacteria (Kamara *et al.*, 2022).

Total bacterial count (TBC) ranged from 20 CFU/100mL (in 27.77% of total samples) to 28 (sample 5), with mean variance (22.22 ± 2.16 SD). There are no strict preamble limits recommended by WHO for TBC in drinking water. High loads of TBC in wells indicate water contamination but do not necessarily reflect pathogenicity of water. However, some studies indicate that the acceptable limit in drinking water is 500 CFU/100 mL (Taghilou *et al.*, 2017). Study on the traditional wells in Gana conducted by Lutterodt *et al.* (2018) found that TBC loads were more than 1000 CFU/100 mL, and were contaminated with total coliforms and *E. coli*. Moreover, rainfall events, surrounding land use and depth of wells contribute more loads of TBC compared with other well-covered and constructed wells (Mile *et al.*, 2012).

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Table 3 A: Details of some physical, chemical and bacterial parameters of targeted wells in Hiznah village, Al-Baha region, Saudi Arabia

Well no.	Parameters								
	Temp. (SU)	pH (SU)	TDS (mg/L)	Conductivity (µs/cm)	Cl ⁻ ((mg/L)	Total hardness as CaCO ₃ (mg/L)	Fe (mg/L)	Nitrate as NO ₃ (mg/L)	Cu (mg/L)
1	20	7.70	690	1380	170.16	496	.08	12.70	.003
2	21	8.00	749	1498	283.60	494	.07	11.50	.003
3	19.5	8.10	856	1712	269.42	628	.11	10.70	.003
4	20	7.70	572	1144	198.52	416	.06	10.30	.003
5	20.5	7.40	788	1576	241.06	612	.06	11.00	.003
6	21	7.80	868	1736	241.06	548	.03	12.10	.003
7	20.5	7.80	750	1500	226.88	548	.02	9.90	.003
8	20	7.90	978	1956	283.60	736	.06	10.30	.003
9	20	7.70	1015	2030	311.96	784	.08	12.10	.003
10	19.5	8.40	676	1352	212.70	492	.07	10.01	.003
11	20	8.10	894	1788	226.88	544	.12	11.00	.003
12	20	7.60	654	1308	212.70	548	.03	9.00	.003
13	18	7.80	404	808	255.24	366	.03	9.10	.003
14	19.5	8.40	246	492	198.52	399	.07	8.70	.003
15	20	8.20	541	1082	172.00	498	.04	10.00	.003
16	19	8.30	537	1074	172.00	580	.02	10.10	.003
17	19	8.00	446	892	172.00	482	.02	9.80	.003
18	19	8.20	431	862	122.00	376	.06	11.20	.003

Mean ± SD	19.80 ± 0.75	7.95 ± 0.29	671.94 ± 212.38	1343.89 ± 424.77	220.57 ± 49.25	530.39 ± 112.44	0.06 ± 0.03	10.53± 1.11	0.003 ± 0.000
Range	18 - 21	7.40 – 8.40	246 -1015	492 - 2030	122 – 311.96	366 - 784	0.02 - 0.12	8.70 – 12.70	0.003 – 0.003
WHO PL	20-25 °C	6.5 - 8.5	500 - 1000	250	250	500	0.3	50	2

WHO: world health organization, PL: permissible limits, SD: standard deviation, SU: standard unit, NA: not applicable.

Table 3 B: Details of some physical, chemical and bacterial parameters of targeted wells in Hiznah village, Al-Baha region, Saudi Arabia.

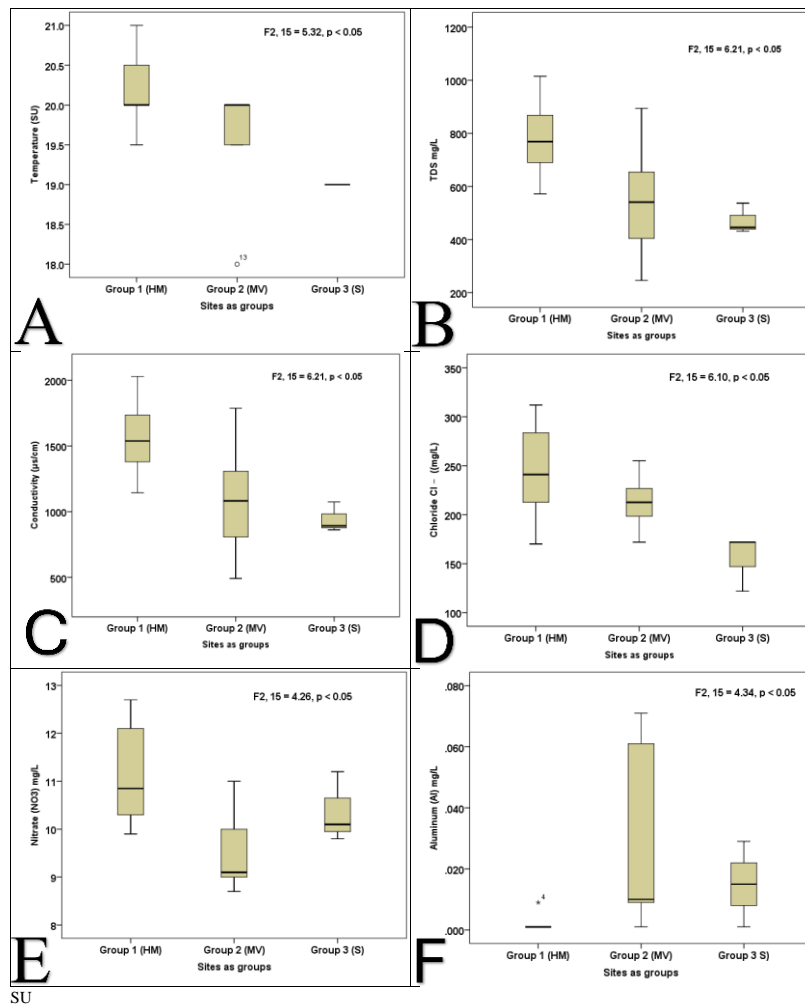
Hiznah wells as groups	Parameters								TBC (CFU/100mL)
	Pb (mg /L)	Hg (mg /L)	Mn (mg/L)	Zn (mg/L)	Al (mg /L)	Cd (mg /L)	TCB (MPN/100mL)	T E.coli (MPN/100mL)	
1	.008	.0006	.001	.029	.001	.008	8	0	20
2	.008	.0006	.001	.028	.001	.008	8	0	22
3	.008	.0006	.001	.040	.001	.008	8	0	24
4	.008	.0006	.001	.028	.009	.008	12	0	22
5	.008	.0006	.001	.048	.001	.008	8	0	28
6	.008	.0006	.001	.049	.001	.008	20	0	24
7	.008	.0006	.001	.041	.001	.008	8	0	22
8	.008	.0006	.001	.039	.001	.008	8	0	22
9	.008	.0006	.001	.045	.001	.008	14	0	22
10	.008	.0006	.001	.029	.001	.008	14	0	26
11	.008	.0006	.001	.680	.009	.008	18	0	22

12	.008	.0006	.001	.042	.001	.008	16	0	20
13	.008	.0006	.001	.029	.071	.008	16	0	20
14	.008	.0006	.001	.014	.061	.008	10	0	22
15	.008	.0006	.001	.028	.010	.008	8	0	20
16	.008	.0006	.001	.055	.001	.008	10	0	20
17	.008	.0006	.001	.500	.015	.008	8	0	22
18	.008	.0006	.001	.042	.029	.008	20	0	22
Mean ± SD	.008 ± .000	.0006 ± .0000	.001 ± .000	.098 ± .182	.012 ± .021	.008 ± .000	11.89 ± 4.47	.00 ± .000	22.22 ± 2.16
Range	.008 - .008	.0006 - .0006	.001 - .001	.014 - .680	.001 - .071	.008 - .008	8 - 20	0 - 0	20 - 28
WHO PL	0.01	0.001	0.4-0.5	0.01-3	0.2	0.003	0	0	N.A.

WHO: world health organization, PL: permissible limits, SD: standard deviation, SU: standard unit, NA: not applicable.

Effects of spatial factors on the variation of environmental parameters

Effects of spatial factors on the variation of physical, chemical and bacterial parameters are presented in Table 2 and figures 2. One –Way ANOVA analysis shows no significant effects of individual sites on the variation of all environmental parameters investigated. However, this analysis shows significant effects of sites as groups on the variation of TDS ($F_{2, 15} = 6.21, p < 0.05$), conductivity ($F_{2, 15} = 6.21, p < 0.05$), chloride ($F_{2, 15} = 6.10, p < 0.05$), nitrate ($F_{2, 15} = 4.26, p < 0.05$), aluminum ($F_{2, 15} = 4.34, p < 0.05$) and water temperature ($F_{2, 15} = 5.32, p < 0.05$). Post hoc comparisons test for TDS, conductivity, chloride, and water temperature revealed significant differences between group 1 (HM) for (TDS: $M = 794.20, SD = 1437.452$, conductivity: $M = 1588.40, SD = 274.904$, chloride: $M = 243.8960, SD = 43.73125$, and water temperature: $M = 20.200, SD = 0.5375$, respectively) and group 3 (MV) for (TDS: $M = 471.33, SD = 57.361$, conductivity: $M = 942.67, SD = 114.723$, chloride: $M = 155.333, SD = 28.86751$, and water temperature: $M = 19.000, SD = 0.0000$, respectively). On the other hand, Post hoc comparisons test indicated that the mean score for nitrate in group 1 (HM) ($M = 11.0610, SD = 0.98786$) was significantly different from wells in group 2 (S) ($M = 10.3667, SD = 0.73711$). However, this test revealed no significant differences between all groups for aluminum. Studying the effect of spatial variation of areas containing groundwater used for drinking or other activities is important for assessing its safety. Groundwater quality varies spatially from one location to another due to geological variations, human and agricultural activities, and hydrological variations (Pacheco Castro *et al.*, 2018). Consequently, spatial variation play an important role on the shift of quality of well waters through affecting physical, chemical (Ababakr *et al.*, 2023), and microbial parameters (Montiel *et al.*, 2023).



SU: standard unit, HM: Hiznah mountain, MV: middle of village, S: shaaf

Figure 2. Variation of temperature (A), TDS (B). Conductivity (C), Cl⁻ (D), NO₃ (E), and Al (F) between sites as groups in some wells in Hiznah village, Al-Baha region, Saudi Arabia during 2025.

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Significant relationships between environmental parameters

Previous studies of groundwater emphasized the interrelationships between different environmental parameters (Jiang *et al.*, 2025; Saalidong *et al.*, 2022; Sahu *et al.*, 2024).

Significant sportsman's correlations coefficient analysis between all environmental parameters are presented in (Table 3), and (Figure 3. & Figure 4.).

A very strong positive relationship was between TDS and conductivity ($r_s = 1.000^{**}$, $p < 0.01$). The study conducted by Verma (2025) on samples from various drinking water sources, revealed a strong positive correlation between conductivity and total dissolved solids (TDS) ($R^2 \approx 0.98$). This study further confirmed the potential of using conductivity as a strong indicator of TDS in drinking water. The strong positive relationship between conductivity and total dissolved solids ($R^2 \approx 0.97$) was revealed in the study conducted by Muhammad (2024) on rainwater samples, and this study concluded that conductivity can be used as an alternative variable to estimate dissolved solids in water. Another study, conducted on several different freshwater sources, concluded that conductivity is the best, fastest, and most reliable method for predicting the total dissolved solids (TDS) content. This conclusion was based on interpreting the approximately 96% variance in TDS content from conductivity values (Thirumalini & Joseph, 2009).

This study revealed slightly decrease in pH with increases of water temperature ($r_s = -.493^*$, $p < 0.05$). Similar result in ground water was obtained by Riedel (2019). The pH of groundwater is indirectly affected by temperature through its effect on mineral solubility and ion exchange (Sajil Kumar *et al.*, 2015).

Strong positive relationship was between TDS and Cl^- ($r_s = .670^{**}$, $p < 0.01$). Moderate to strong positive correlation between TDS and Cl^- has been observed by Mohallel (2025) in some groundwaters in western desert, Egypt. The Cl^- is one of different anions that contribute of the increased concentration of TDS in groundwater and originally comes from different sources, such as anthropogenic pollution and halite dissolution (Fidelibus *et al.*, 2025).

Strong positive correlation was also observed between TDS and total hardness as $CaCO_3$ ($r_s = .789^{**}$, $p < 0.01$). Many studies reflect the same result of strong positive correlation between TDS and total harness in different types of water sources, such as groundwater (Priyadarshane *et al.*, 2024) and mountain stream tap water (Rangpan & Khaemoh, 2022). The combination between calcium and magnesium in well waters reflects the overall hardness ($CaCO_3$), and its increase mainly attributable to carbonate and halite dissolution (Rebello *et al.*, 2020).

This study reflected positive relationship between TDS and NO_3 ($r_s = .598^{**}$, $p < 0.01$). Similar result has been found by A. Mamun (2025) in some groundwater northeastern region of Saudi Arabia. Fertilizers, manure and wastewater are the most sources for NO_3 in groundwaters which in turn contributes partially to increases of TDS with other dissolved ions. (Gao *et al.*, 2024).

This research, on the other hand, revealed strong negative correlation between TDS and Al ($r_s = -.705^{**}$, $p < 0.01$). What determines the relationship between TDS and aluminum is not simple dissolution. So, several factors control the decrease in aluminum with increasing TDS concentration, such as, precipitation, adsorption and metal equilibrium reactions (Hao *et al.*, 2024). The study conducted by Salem *et al.* (2022) in groundwater in UAE, should different correlation behaviors of Al in relation to TDS, indicating that trends of TDS are not primary controlled by Al concentrations.

Strong positive relationship between TDS and water temperature was observed in this study ($r_s = .646^{**}$, $p < 0.01$). Similar result was found by Zaidi *et al.* (2022) on groundwater in Midyan region, Saudi Arabia found, indicating that higher water temperature enhances mineral dissolution which in tern leads to increase TDS values. However, study on shallow wells in the north coast region, in Pacar village conducted by Zulfa. (2019) demonstrated that no significant relationship between TDS and water temperature and attributed that to factors, such as seawater leakage.

The Cl^- was positively correlated with total hardness as $CaCO_3$ ($r_s = .512^*$, $p < 0.05$). Many studies reveled the same result of positive correlation between chloride and total hardness (Bairwa *et al.*, 2024; Hota *et al.*, 2023; Obeidat *et al.*, 2020). Both natural geological factors and anthropogenic contamination determine the relationship between Cl^- and total hardness in groundwater. Presence of calcium and magnesium elevated total hardness, while Cl^- ion arises from halite dissolution and anthropogenic sources (Hota *et al.*, 2023).

This study revealed strong negative correlation between total hardness and Al ($r_s = -.766^{**}$, $p < 0.01$). Many studies demonstrated that the correlation between total hardness and Al are usually indirect and depend strongly on some factors, such as pH, natural geogenic factors and geochemical operations. For example, water hardness near alkaline

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pH condition can limit Al solubility and in turn lead to negative correlation between hardness and Al (Al-Ahmadi, 2013; He *et al.*, 2021).

Negative relationship was also between Al and temperature ($rs = -.566^*$, $p < 0.05$). The study conducted by Popugaeva *et al.* (2020) emphasized that water temperature is indirect factor affecting Al solubility. It controls of some variables, such as pH buffering and mineral dissolution. For example, in acidic groundwater, high temperature can enhance Al solubility and elevated its concentration compared with alkaline pH conditions (Akbari *et al.*, 2018).

There was positive correlation between Fe with NO₃ ($rs = .496^*$, $p < 0.05$). This result is in contrast with many field studies that reported negative correlation between Fe and NO₃ in redox groundwaters. For example, the study conducted by Pathak & Hiratsuka (2010) in shallow wells in Kathmandu found that high Fe values synchronized with low NO₃ concentrations. Redox conditions and biogeochemical processes govern the relationship between Fe and NO₃ in groundwater (Xia *et al.*, 2022). This negative relationship between Fe and NO₃ is linked to denitrification process, using NO₃ as an electron acceptor and Fe as an electron donor by bacteria under anoxic conditions (Margalef-Marti *et al.*, 2020).

Table 3. Relationship between some investigated environmental parameters in some wells in Hiznah village, AL-Baha region, Saudi Arabia

Parameter	pH (SU)	TDS (mg/L)	Conductivity (µs/cm)	Cl- (mg/L)	Total hardness as CaCO ₃ (mg/L)	Fe (mg/L)	NO ₃ (mg/L)	Al (mg/L)	Temperature (SU)
pH (SU)	-	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	$rs = -.493^*$, $p < 0.05$
TDS (mg L ⁻¹)	N.S.	-	$rs = 1.000^{**}$, $p < 0.01$	$rs = .670^{**}$, $p < 0.01$	$rs = .789^{**}$, $p < 0.01$	N.S.	$rs = .598^*$, $p < 0.01$	$rs = -.705^*$, $p < 0.01$	$rs = .646^{**}$, $p < 0.01$
Conductivity (µs/cm)	N.S.	$rs = 1.000^*$, $p < 0.01$	-	$rs = .670^{**}$, $p < 0.01$	$rs = .789^{**}$, $p < 0.01$	N.S.	$rs = .598^*$, $p < 0.01$	$rs = -.705^*$, $p < 0.01$	$rs = .646^{**}$, $p < 0.01$
Cl ⁻ (mg/L)	N.S.	$rs = .670^{**}$, $p < 0.01$	$rs = .670^{**}$, $p < 0.01$	-	$rs = .512^*$, $p < 0.05$	N.S.	N.S.	N.S.	N.S.
Total hardness as CaCO ₃ (mg/L)	N.S.	$rs = .789^{**}$, $p < 0.01$	$rs = .789^{**}$, $p < 0.01$	$rs = .512^*$, $p < 0.05$	-	N.S.	N.S.	$rs = -.766^*$, $p < 0.01$	N.S.
Fe (mg/L)	N.S.	N.S.	N.S.	N.S.	N.S.	-	$rs = .496^*$, $p < 0.05$	N.S.	N.S.
NO ₃ (mg/L)	N.S.	$rs = .598^{**}$, $p < 0.01$	$rs = .598^{**}$, $p < 0.01$	N.S.	N.S.	$rs = .496^*$, $p < 0.05$	-	N.S.	N.S.

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Al (mg/L)	N.S.	rs = -.705**, p < 0.01	rs = -.705**, p < 0.01	N.S.	rs = -.766**, p < 0.01	N.S.	N.S.	-	rs = -.566*, p < 0.05
Temperature (SU)	rs = -.493*, p < 0.05	rs = .646**, p < 0.01	rs = .646**, p < 0.01	N.S.	N.S.	N.S.	N.S.	rs = -.566*, p < 0.05	-

Key symbols: SU: standard unit, N.S.: not significant, *rs*: Superman's rank correlation.

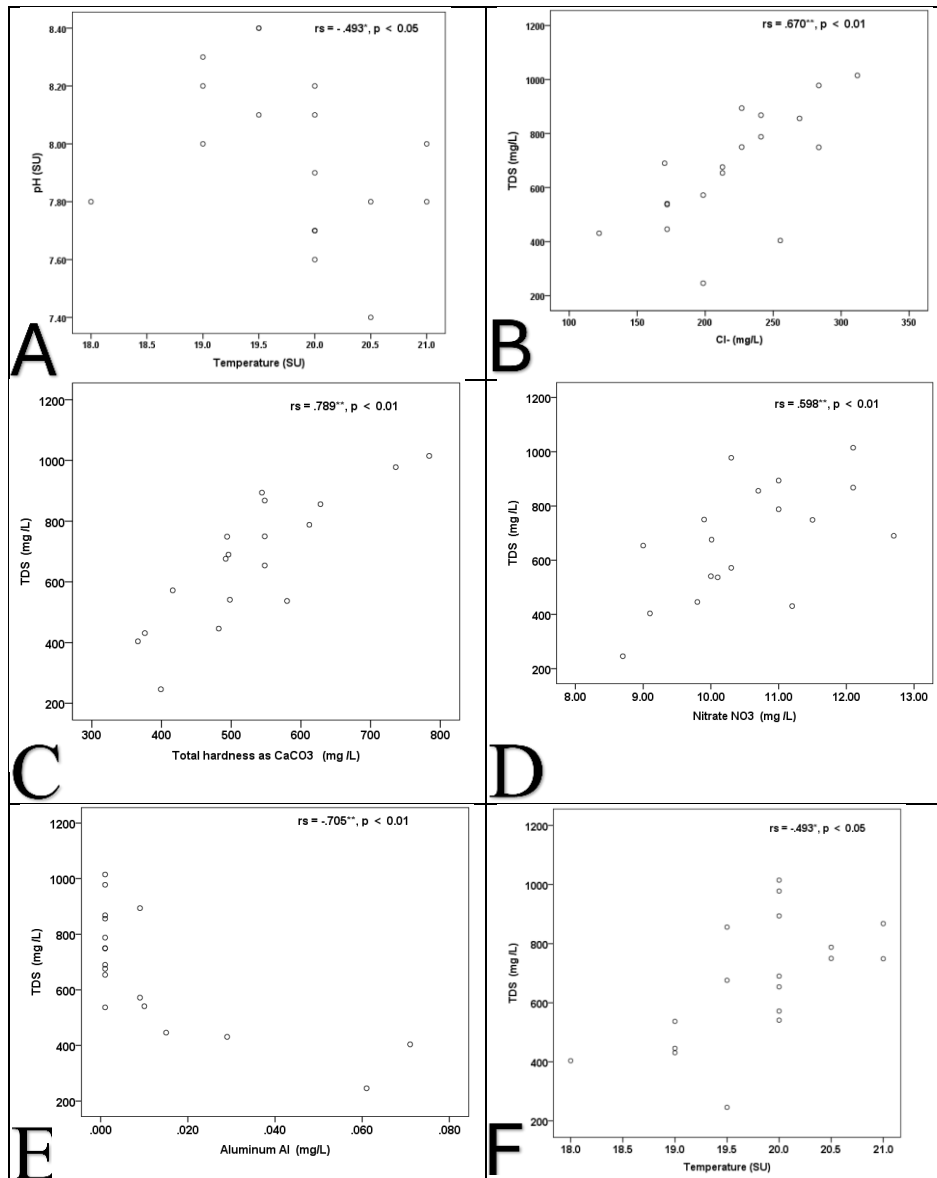


Figure 3. Relationships between (Temperature and pH) (A), (Cl⁻ and TDS) (B), (total hardness and TDS) (C), (NO₃ and TDS) (D), (Al and TDS) (E), and (temperature and TDS) (F) in some wells in Hiznah village, Al-Baha region, Saudi Arabia during 2025

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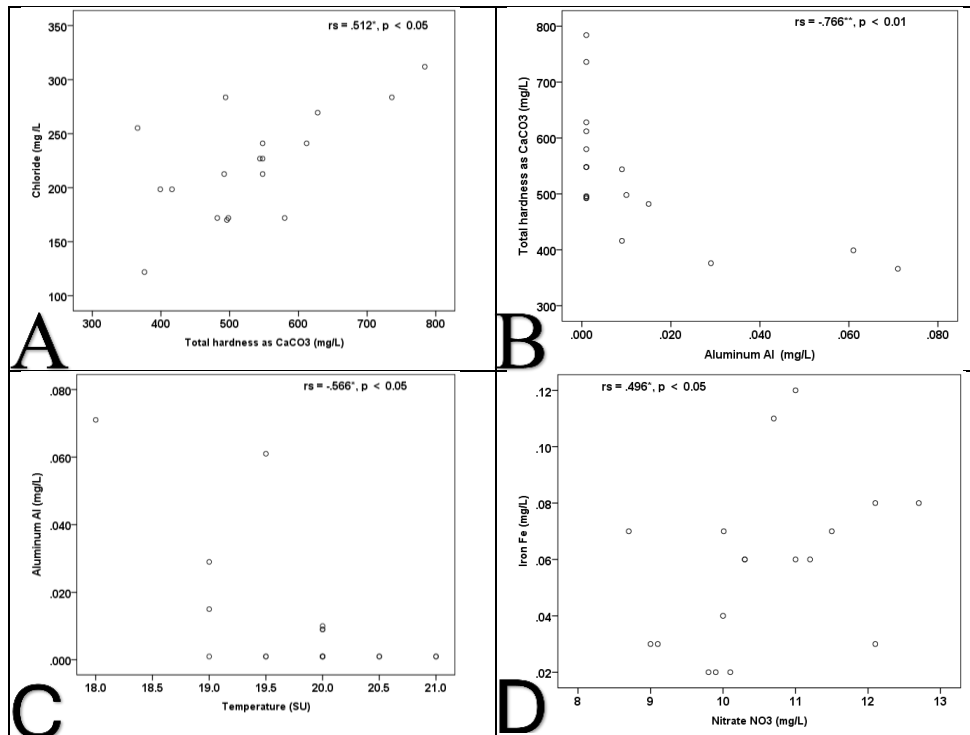


Figure 4. Relationships between (total hardness and Cl^-) (A), (Al and total hardness) (B), (temperature and Al) (C), and (NO_3 and Fe) (D) in some wells in Hiznah village, Al-Baha region, Saudi Arabia during 2025

Conclusion:

The present study found that temperature, pH, TDS, Fe and NO_3 were within acceptable limits recommended by WHO in all samples. On the other hand, conductivity, Cl^- and total hardness exceeded the permissible limits referenced by WHO in (100%, 27.7% and 50% of samples, respectively). In addition, heavy Cu, Pb, Hg, Mn and Cd presented in very small concentrations and were below limits of WHO standards for drinking water, while Zn and Al were within acceptable limits for such WHO standards. This research also demonstrated that all wells were contaminated with TCB, which needs disinfection before human consumption, while all samples were free of *Esherishia coli*. In addition, TBC loads presented in low concentrations in all wells and do not necessarily reflect the risk for human health. Moreover, this study reflected significant differences between sites as groups, for example, the significant variation of TDS, conductivity, chloride and water temperature. TDS, conductivity, chloride, and water temperature between group 1 (HM) and group 3 (MV). Also, there was a significant nitrate variation between group 1 (HM) and group 2 (S). The present research also, reflected significant positive correlation which varied from moderate between (Fe and NO_3) and (Cl^- and total hardness) to strong positive correlation between (TDS and conductivity), (TDS and Cl^-), (TDS and total hardness), (TDS and NO_3) and (TDS and water temperature). The significant negative relationships also varied from moderate between (Al and water temperature) and (pH and water temperature) to strong negative relationships between (TDS and Al) and (total hardness and Al). This study recommends that the residents of Hiznah village pay close attention to these wells, which may be used for drinking or other purposes that could affect their health. The study also recommends treating the village's well water before use. Furthermore, it recommends conducting further tests and studies on the village's well water to identify the presence of other types of total coliform bacteria that could affect consumer health.

Conflicts of Interest

The author declares the absence of any conflicts of interest.

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Data Availability

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

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