NTU Journal of Pure Sciences
Double Blind Peer Review Journal
ISSN: 2789-1089 EISSN: 2789-1097
Available Online: https://journals.ntu.edu.iq/index.php/NTU-JPS
Volume 5, No. 1, 2026

Original Article

Spatial Analysis of Qualitative Features of Groundwater for Human Uses: A Case Study of Ain Al-Hussan Villages, Sinjar District, Northwestern Iraq

Reem Adnan Al-Shanoona [a, *]

[a,] Department of Biology, College of Education for Pure Science, University of Mosul, 41002 Mosul, Iraq.

*Corresponding: Reem Adnan Al-Shanoona, Email: reem.alshanona@uomosul.edu.iq

Received: 07 May 2025
Accepted: 18 June 2025
Published: 12 April 2026
DOI: https://doi.org/10.56286/6rdzrg14
Article ID: 1403

Abstract

The current study was conducted to determine the suitability of the water sources for human use in the villages of Ain al-Hussan affiliated with Sinjar District in Nineveh Governorate. Ten sampling sites were chosen, during the summer and autumn seasons, to conduct some qualitative tests such as pH, electrical conductivity, total hardness, and total number of bacteria, in addition to some positive and negative ions. The logarithmic model was also applied to determine the quality of water sources. The results indicated an increase in the concentration of sulfate ions and the total number of bacteria, which reached 1041 mg/L and 95056 cells. ml-1, respectively, exceeding the permissible limits for drinking and domestic uses, as confirmed by the results of the Water Quality Index (WQI), which ranged from (91.83 to 261.2), to classify the quality of the studied water as unfit for human consumption in its current state, as eighty percentof it was unfit for human consumption, and the rest was of very poor quality.

Keyword: logWQI, Groundwater quality, Water sources in Ain Al-Hussan villages

Introduction

Today, our country suffers from a water crisis that cannot be ignored without finding alternatives and solutions due to the shortage of water in the Tigris and Euphrates rivers and their tributaries inside Iraq. In such circumstances, it is necessary to use the principles of good water management and storage, such as rainwater harvesting and attention to dams on permanent rivers to store water to benefit from it in dry seasons, especially in central and southern Iraq, as well as the scientific exploitation of groundwater, with the use of modern irrigation methods to keep pace with the water scarcity crisis, and the most important thing is to rationalize water consumption [1]. Many countries in arid and semi-arid regions meet their water needs from groundwater, which is extremely important because approximately (33%) of the population depends on it, as the total use of groundwater is estimated at (65%) for drinking and domestic uses, (20%) for agricultural purposes and the rest for industrial fields [2, 3, 4].

Therefore, preserving it from pollution and tampering is of utmost importance; as the quality of water is affected by daily human activities and unfriendly agricultural methods that lead to the leakage of wastewater, fertilizers, pesticides, and agricultural wastewater contaminated with animal waste, especially those located near population centers. All of this deteriorates the quality of water and becomes a source of transmitting pathogens to humans and livestock. Unfortunately, reports and statistics from the World Health Organization indicate that more than 80% of disease cases and 33% of deaths in developing countries were due to waterborne epidemics, with the number of deaths estimated at about 230,000 children under the age of five annually due to contamination of drinking water with sewage, especially in poor communities, where cases of diarrhea, polio, viral hepatitis, *Salmonella typhi*, and *Vibrio cholera*.

Iraqi groundwater is characterized by high levels of salinity, total hardness, and sulfate ions due to the nature of geochemical reactions that may occur in geological formations during the passage of water through them, in addition to the waste of human activities that may reach groundwater. The presence of pesticides in water and nitrate compounds may pose health risks to consumers such as bladder, rectal, and colon cancer, miscarriage for pregnant women, as well as the possibility of mental retardation in newborns, etc. [3, 5, 6, 7, 8, 9]. High levels of sulfate ions in water cause a bitter taste and diarrhea, especially when the accompanying cation is magnesium. Therefore, periodic studies should be conducted on the quality of water resources. There are many studies conducted in Nineveh Governorate on the quality of groundwater in the Shuwaira area, Tal Afar district, using the Canadian index, which indicated that it is unsuitable for drinking and domestic use due to high salts, total hardness, sulfate ions, and microbial contamination [5]. The quality of groundwater for drinking using the Water Pollution Index (WPI) in Wana district, located northeast of Mosul, which indicated that its quality has deteriorated and is unsuitable for drinking in its current state [10]. The study recommended the use of some simple techniques such as slow freezing, thawing, or solar treatment to improve the quality of water for drinking [11]. Therefore, the current study was intended to evaluate the quality of water sources in the villages of Ain al-Hussan for drinking and domestic uses.

Materials and Method

Description of the villages of Ain Al-Hussan

The study sites are located in the Al-Jazeera sector, northwest of Iraq, which occupies most of the area of Nineveh Governorate, including the villages of Ain Al-Hussan (Southern Ain Al-Hussan, Middle Ain Al-Hussan and Northern Ain Al-Hussan), affiliated with Sinjar District (Northern, Central and Southern Ain Al-Hussan), which are located between longitudes (42.1885-42.2204) east and latitudes (36.3046-36.3561) north. The study area is approximately 90 km from the center of Mosul. The local population works in agriculture, livestock and poultry farming, as there are many orchards of different plant species such as olives, grapes, pomegranates and vegetables, in addition to livestock and poultry farming. Table 1 and the Fig.1 show some characteristics of the studied sites.

Geological description of the study sites

Al-Jazeera sector consists of the Fatha Formation (Middle Miocene) formations, which consist of layers of calcite, dolomite, gypsum evaporate rocks $CaSO_4.2H_2O$, halite (NaCl) and anhydrite (CaSO4). In the village of Ain Al-Hussan, modern deposits are exposed on the surface, which are clastic deposits consisting of clays, silts and rock fragments with a thickness ranging from approximately 10 to 12 meters. This is followed by the layers of the Injana Formation, which consists of successions of sandstone, clay and silts with a thickness ranging from approximately more than 100 meters in the southern Ain Al-Hussan and approximately 50-60 meters in the northern Ain Al-Hussan. This is followed by the layers of the Fatha Gypsum Formation, which are rock layers consisting of successions, most of which are gypsum layers interspersed with thin layers of clays, marls and limestone [5, 12, 13].

Table 1. Coordinates and depths of the wells studied.

Sites	*Depth*	*Villages*	*Coordinates*	
			E	N
St1	50 m	Southern Ain Al-Hussan	42°220460	36°304636
St2	35 m		42°215740	36°310066,
St3	40 m		42°212618	36°311950
St4	40 m	Middle Ain Al-Hussan	42°211362	36°316428
St5	100 m		42°197393	36°333888
St6	35 m	Northern Ain Al-Hussan	42°202757	36°342444
St7	29 m		42°197704	36°344847

St8	40 m	42°197897	36°343231,
St9	fountain	42°194260	36°344138
St10	30 m	42°188581	36°356125

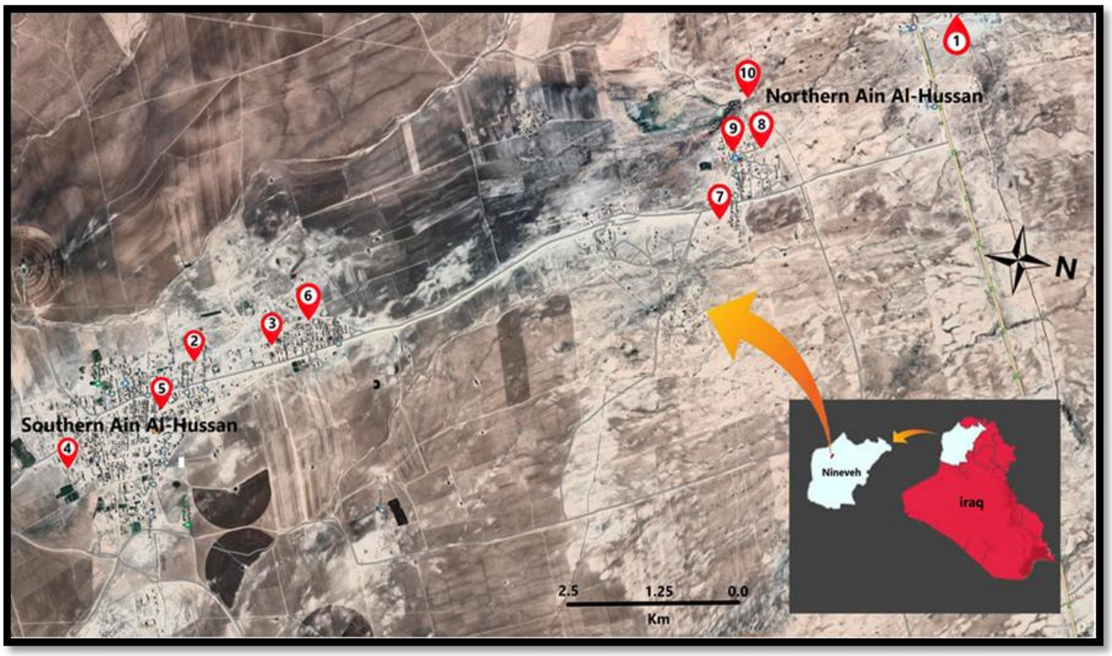

Figure 1. Satellite map showing the study area and the locations of water sources in the villages of Ain Al-Hussan.

Sample Collection and Analysis

Ten sites were identified for the current study, where sixty water samples were collected at specific periods during the summer and fall seasons in clean plastic bottles, in addition to collecting samples for bacterial tests using autoclave glass bottles. The samples were placed in a cooled and dark box until reaching the Environmental Laboratory of the College of Education for Pure Sciences at the University of Mosul to conduct chemical and bacterial tests: pH, T. Alkalinity (T. Alk.), Total hardness (TH), chloride, sulfate, phosphate, nitrate, total number of bacteria (TPC), while physical tests such as water transparency, temperature, electrical conductivity (EC25) were measured in the field during the collection of water samples based on international standard methods [14, 15]. In addition to conducting statistical analysis to find the Pearson correlation coefficient between the studied parameters.

Qualitative assessment of water

In order to evaluate the quality of water, whether groundwater or surface, many water quality indicators are used globally, such as the Canadian index, Organ, NSF, sub-index model, logarithmic index, etc., because they are an effective means of evaluation and their results are understandable and easy instead of large numbers of data. It is also preferable to choose the most important and influential parameters on the quality of the studied water, and it is important not to overdo the parameters used in calculating the index to prevent confusion in the results [5, 11, 16, 17]. In our current study, the logarithmic model for water quality (WQI) was applied to eleven properties and compared with the global standard limits for drinking water [18] using the equations below [10, 19, 20, 22]:

$$WQI = \text{Antilog}\ \Sigma\ (Wi \times \log10Qi)$$

$$K = \Sigma \frac{1}{\frac{1}{Vs1} + \frac{1}{Vs2} + + + \frac{1}{Vi}}$$

$$Wi = K/\ Vsi$$

$$Qi = [Va - Vi] / [Vsi - Vi]$$

Here, Wi= unit weight of the ith parameter, K= proportion constants., Qi: sub index corresponding to the ith parameter Va: actual value of each parameter. Vi= the deal value of each1 parameter (for pH=7.0, while other parameters are equal to zero. Vs= the internationally recommended standard1 value, as shown in Tab. 2.

After finding the water quality index (WQI) values, the water quality is classified into five categories: excellent quality water (0 to 25), good quality water (26 to 50), poor quality water (51 to 75), very poor-quality water (76 to 100), and water unsuitable for use (more than 100) [22].

Table 2. Standard limits (Vsi)*, and weight (Wi) for each parameter for drinking and household uses.

Param.	*Units*	*Vsi*	*Wi*
T.C	˚C	25	0.100790870
Ph		6.5- 8.5	0.296443734
EC_{25}	uS. Cm	1400	0.001799837
T. Alk.	mg. l^{-1}	200	0.012598859
T.H	mg. l^{-1}	500	0.005039543
Na	mg. l^{-1}	200	0.012598859
Cl	mg. l^{-1}	250	0.010079087
SO4	mg. l^{-1}	400	0.006299429
PO4	mg. l^{-1}	10.0	0.251977174
NO3	mg. l^{-1}	50.0	0.050395435
T.P.C	Cell. ml^{-1}	10.0	0.251977174
	∑		1.000000000

Results and Discussion

The results of the logarithmic index for evaluating water resources in Ain Al-Hussan villages showed a deterioration in their quality, with values fluctuating between (97.3 to 201.1), where 80% of them were in the category of water unfit for drinking and domestic use, and the rest were in the category of very poor water, as shown in Tab. 3. It was also found that the spring water (ST9) was one of the most deteriorated sites studied, as the index value reached 261.2, due to the high levels of some parameters, especially sulfate ions and the high total number of bacteria, which reached (95.5) × 102 cells. ml-1 at a rate of (37.7) × 102 cells. ml-1 as a result of its direct exposure to microbial pollution by animal and human waste.

Table 3. Results values of (Wi*logQi), water quality index and water status in the villages of Ain Al-Hussan.

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
TC	0.195	0.195	0.194	0.195	0.195	0.196	0.196	0.196	0.192	0.195
PH	0.567	0.565	0.562	0.565	0.567	0.567	0.565	0.565	0.569	0.564
EC	0.004	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.004	0.003
T. Alk	0.024	0.024	0.024	0.024	0.024	0.023	0.024	0.024	0.024	0.021
T.H.	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.008	0.009	0.009
Na	0.021	0.020	0.019	0.020	0.019	0.019	0.018	0.018	0.016	0.021
CL	0.017	0.017	0.014	0.014	0.013	0.014	0.013	0.012	0.014	0.015
SO4	0.014	0.015	0.014	0.014	0.014	0.014	0.014	0.015	0.015	0.014
PO4	-0.04	-0.07	-0.08	-0.07	-0.05	-0.07	-0.05	-0.05	0.173	-0.01
NO3	0.070	0.070	0.069	0.070	0.069	0.066	0.065	0.068	0.061	0.055
T.P.C	1.124	1.338	1.415	1.116	1.169	1.483	1.353	1.358	1.341	1.097
Σ	2.008	2.182	2.247	1.963	2.028	2.322	2.209	2.212	2.417	1.988
WQI	101.8 Unfit	152.0 Unfit	176.5 Unfit	91.83 V. P.	106.8 Unfit	210.1 Unfit	161.7 Unfit	162.9 Unfit	261.2 Unfit	97.30 V. P.

V. P.: Very Poor Quality

As shown in Tab. 3 and Fig. 2, the same is true for the rest of the wells studied due to the possibility of human and animal waste leaking into the well water because all the samples studied exceed the global limits allowed for human use, as the rates fluctuated between 1.1 - 145 x 104 cells. ml-1, which was negatively reflected in the values of (logQi).

Table 4. Range of water source analysis results for Ain Al- Hussan villages (ppm), except EC25 and TPC.

Parameters / *Sites*	*T˚C*	*pH*	*EC*	*T. A*	*T.H*	*SO_4*	*Cl*	*Na*	*NO_3*	*PO_4*	*TPC*

St1	Min	20.5	6.75	1178	140	180	343	105	91.0	9.56	0.02	2.94
	Max	22.0	7.19	1294	180	340	995	135	102	16.03	0.15	44.7
St2	Min	20.5	6.69	1178	160	170	740	105	71.0	11.6	0.01	2.39
	Max	22.0	6.99	1240	190	310	913	125	83.0	12.4	0.13	72.2
St3	Min	20.0	6.56	1178	100	190	308	45.0	53.0	10.7	0.02	5.99
	Max	22.0	6.79	1166	180	390	926	70.0	73.0	11.8	0.12	88.6
St4	Min	20.0	6.65	1178	150	220	546	55.0	61.0	11.7	0.01	1.10
	Max	22.5	7.08	1232	190	350	910	80.0	87.0	12.1	0.06	42.2
St5	Min	21.0	6.69	1178	140	150	529	45.0	55.0	11.6	0.02	1.76
	Max	22.0	7.21	1188	190	380	894	78.0	77.0	12.0	0.13	42.7
St6	Min	20.5	6.81	1178	100	180	629	40.0	46.0	7.70	0.01	6.31
	Max	23.0	7.18	1160	180	350	843	50.0	78.0	11.8	0.14	119
St7	Min	20.7	6.70	1178	170	201	522	35.0	49.0	7.83	0.01	24.6
	Max	23.0	6.93	1120	180	310	1001	95.0	66.0	11.6	0.12	105
St8	Min	20.0	6.68	1178	130	190	592	25.0	42.0	10.2	0.03	2.46
	Max	23.0	6.95	1096	160	250	1041	47.0	61.0	11.5	0.10	145
St9	Min	19.0	6.84	1178	100	200	516	40.0	31.0	7.70	0.03	1.20
	Max	20.0	7.27	1145	200	350	1028	70.0	49.0	8.56	0.49	95.5
St10	Min	18.5	6.60	1178	70.0	220	445	45.0	88.0	5.66	0.01	1.61
	Max	25.0	6.95	1207	110	300	925	85.0	99.0	7.60	0.18	43.6

EC_{25}: us. cm^{-1}., TPC: $\times 10^2$cell. ml^{-1}

Also, 60% of the water samples exceeded the total alkalinity levels of the recommended global limits, while 90% of the samples exceeded the sulfate concentrations of the global limits [18]. This increase may be due to the reactions and decomposition processes that occur when water passes through the layers of geological formations, especially the formation of the opening rich in gypsum and anhydrite rocks, as in the following equations [23, 24]:

$$2CaSO_4 + 3[CH_2O] \rightarrow 2CaCO_3 + 2S + CO_2 + 3H_2O$$

$$S^{=} + 2H^{+} \rightarrow H_2S + 3O_2 \rightarrow 2SO_2 + 2H_2O$$

$$2H_2SO_3 + O_2 \rightarrow 2H_2SO_4$$

Despite these interactions and the formation of strong acids, the pH values did not drop to very low levels due to the high susceptibility of Iraqi water and soil to (ANC) acid.

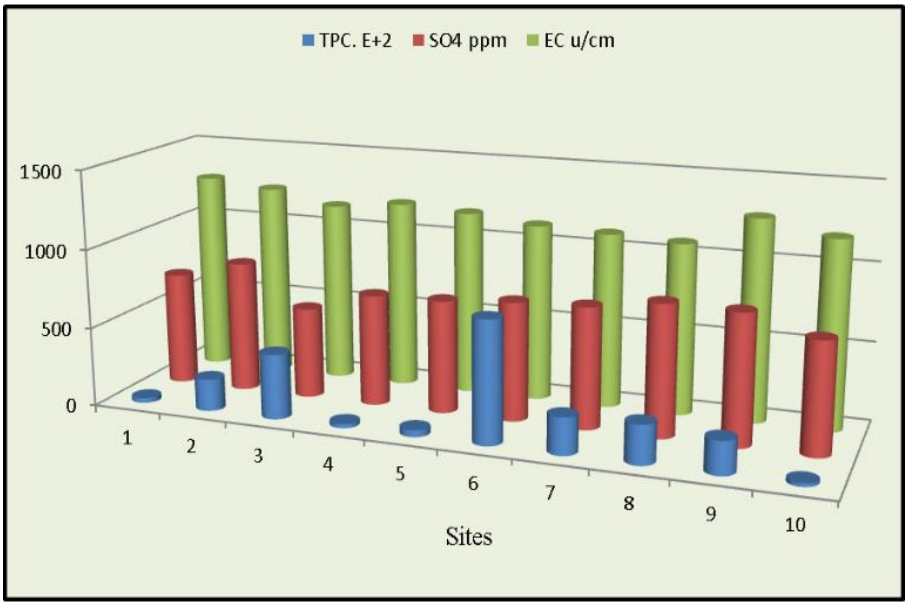

Figure 2. Average total bacterial count ($\times 10^2$ cells. ml^{-1}), conductivity and sulfate ion concentration for the studied water resources.

neutralization capacity [25,26, 27], as the values fluctuated between (6.60-7.27) and at a rate of (6.76 ± 0.11 to 7.12 ± 0.16) as shown in Tab. 4 and Fig. 3.

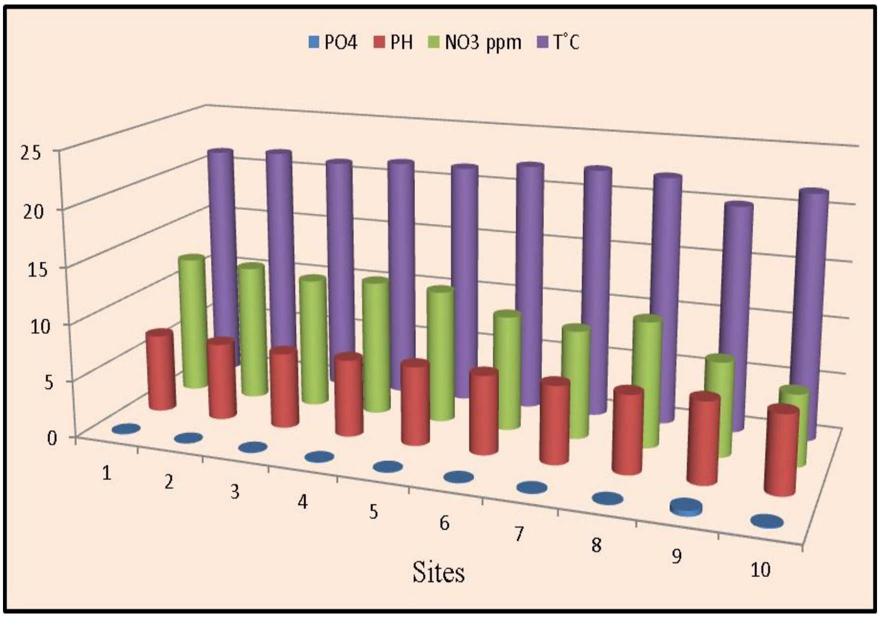

Figure 3. Average values of Temperature, pH, nitrate and phosphate ions for the studied water resources.

The results shown in Table 4 and Fig. 2 show a relative increase in electrical conductivity values, despite not exceeding the permissible limits for drinking, ranging between (1145-1240) Us. cm^{-1}, at a rate of (1067 ± 41.9 to 1273 ± 22.6). This increase is attributed to gypsum and anhydrite rocks [28, 29].

The results of the Peterson correlation coefficient test shown in Table 5 indicate a significant relationship at the significance level ($p \leq 0.05$)between the total number of bacteria and pH, chlorides and nitrates, and at the probability level ($P \geq 0.01$) with total hardness and sodium ions. Also the same is true, between electrical conductivity and nitrate ions at a probability level of ($p \leq 0.01$) and sulfates at a probability level of $P \geq 0.05$.

Table 5. Pearson correlation coefficient for the studied groundwater parameters.

Param.	*TC*	*PH*	*EC25*	*T.H*	*T.A*	*Na*	*NO3*	*Cl*	*SO4*	*PO4*	*TPC*
TC	1.00										
PH	-.704	1.00									
EC25	.454	-.046	1.00								
T.H	-.960	.587*	-.288	1.00							
T.A	.443	-.653	-.463	-.694	1.00						
Na	-.645	.484	.672*	.892*	-.876	1.00					
NO3	-.033	.108	.827*	.881*	-.643	.673*	1.00				
Cl	-.868	.875*	.885*	.469	-.533	.586*	.254	1.00			
SO4	-.843	.557*	.576*	.805*	-.008	.724*	.170	-.814	1.00		
PO4	-.084	.666*	.054	.619*	-.466	.046	-.207	.223	.115	1.00	
TPC	-.595	.575*	.281	.779*	-.953	.969**	.599*	.553*	-.116	.280	1.00

For the same reasons above, the total hardness levels rise relatively to reach rates of 48.2 (220 ± 48.2) mg. l^{-1}. It is also noted from the Peterson coefficient table that there is a significant correlation between the total hardness, nitrate ions, and the total number of bacteria at a probability level of ($P \geq 0.01$). As for both chloride and sodium ion levels, they were within the permissible limits, as their rates did not exceed (75.0 ± 16.4 and 99.0 ± 4.56) mg. l^{-1}, respectively, as in Fig. 4.

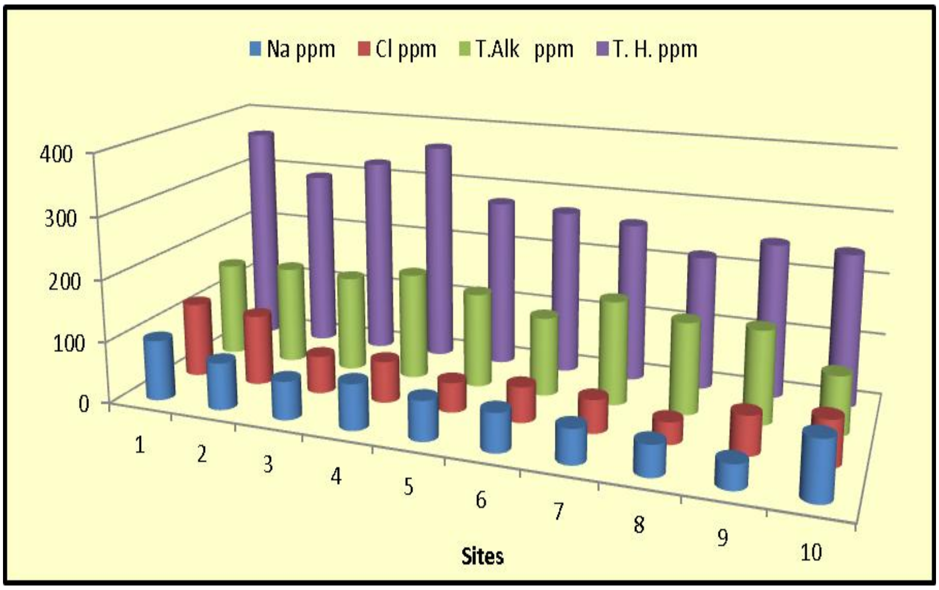

Figure 4. Average values of Na, Cl, T. Alkalinity and T. Hardness for the studied water resources.

This relative increase is due to the geological nature of the study area. Finally, the nutrients represented by nitrates and phosphate ions, iis found in Fig. 3 which reveals that their rates fluctuate between 12.2 ±.35 and 6.4 ±0.79 to ± 0.02 to 0.08 ± 0.05 (0.02 mg respectively), and it was noted that the concentrations of phosphate ions decreased due to their ability to precipitate in the form of calcium phosphate as well as their adsorption on the surfaces of colloidal particles, while a relative increase in nitrate ions is noted despite being within the globally recommended limits, as their high concentrations cause health risks such as cancer, birth defects in newborns, and miscarriages in pregnant women [30].

In general, the temperatures were relatively constant throughout the study period, despite the high air temperature, which did not exceed 22.0 degrees, in addition to the fact that the changes in water temperature were relatively small. This situation was indicated by both [10, 31].

Conclusion and Recommendation

The results of the study of groundwater showed high concentrations of sulfate ions and total bacterial counts, and this was also confirmed by the results of the statistical analysis using Peterson's correlation coefficient at the level ($P > 0.05$), as it exceeded the permissible limits for drinking, which negatively affected the values of WQI to indicate that the quality of the studied water is unfit for drinking and human uses, because of bacterial contamination and sulfate ion, whose results this study aims to address by some techniques. Yet, the temperature, pH value, phosphate ions and nitrates are within the permissible specifications. These techniques can be exposing water to solar radiation or the slow freezing and melting technique.

Acknowledgments

The researchers extend their thank and appreciation to the presidency of the University of Mosul, represented by Professor Dr. Wahid Mahmoud Rammo, for his continuous support, provision of all research needs and conducting experiments and analyses in the Environmental Laboratory in the College of Education for pure science.

Competing Interests

There are no competing interests.

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