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Sub-Index model to assess groundwater water quality for drinking and civil uses

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ABSTRACT: The current study aims to assess groundwater quality for drinking and various domestic uses for selected wells from the district of Tal Abta and some of its affiliated villages located southwest of Mosul, Iraq. As samples were collected from ten wells distributed randomly in the study area, starting from summer until winter, with ten replicates for each well, physical, chemical and bacterial tests were conducted: temperature, electrical and chemical conductivity such as pH, total alkaline T. alkali, total hardness T. Hardness, phosphate ions PO_4^{-3}, sodium Na+, chloride, Cl^-, sulfate SO_4^{-2}, nitrate NO_3^- and the total number of bacteria TPC, with the application of the sub-index model to evaluate the quality of water for drinking and civil use. The results of the Water Quality Index (WQI) indicated a deterioration in the quality of the studied groundwater, as the values ranged between (73.5 to 1538), so all studied samples are considered (Very Poor to Unfit quality) for drinking and civil uses; this deterioration is due to the high levels of Electrical conductivity, total hardness and sulfate ions, which amounted to (5994) uS cm^{-1} and (6420-2130) mg L^{-1}, respectively, with a high total number of bacteria (TPC), which reached (1611) cells mL^{-1}.
Keywords: drinking water quality; water quality index; Tal-Abtah district; Mosul city – Iraq.

Modelo de subíndice para avaliar a qualidade da água de lençol freático para consumo e uso civil

RESUMO: O presente estudo visa avaliar a qualidade da água subterrânea para consumo humano na forma de bebida e vários usos domésticos, provenientes de poços selecionados do distrito de Tal Abta e algumas de suas aldeias afiliadas localizadas a sudoeste da cidade de Mosul, Iraque. Foram coletadas amostras de dez poços distribuídos aleatoriamente na área de estudo, no verão e no inverno, com dez repetições para cada poço. Foram realizados testes físicos, químicos e bacterianos, com base nas seguintes variáveis: temperatura, condutividade elétrica e química como pH, T alcalino total. álcali, dureza total T, Dureza, íons fosfato PO_4^{-3}, sódio Na+, cloreto, Cl-, sulfato SO_4^{-2}, nitrato NO_3^- e o número total de bactérias TPC; posteriormente aplicou-se um modelo de sub-índice para avaliar a qualidade da água para beber e uso civil. Os resultados do índice de qualidade da água (IQA) indicaram uma deterioração da qualidade das águas subterrâneas estudadas, pois os valores variaram de 73,5 a 1538, portanto todas as amostras estudadas são consideradas com qualidade “muito ruim” a “inadequadas” para consumo humano e uso civil. Essa deterioração se deve aos altos níveis de condutividade elétrica, dureza total e íons sulfato, que totalizaram 5994 uS cm^{-1} e 6420-2130 mg L^{-1}, respectivamente, com elevado número total de bactérias (TPC), que atingiu 1611 células mL^{-1}.
Palavras-chave: qualidade de água potável; índice de qualidade de água; distrito de Tal-Abtah; cidade de Mosul – Iraque.

1. INTRODUCTION

One of the most important pillars of national security is the provision of water resources and their proper management, especially in arid and semi-arid regions, mainly in countries whose water resources come from outside their territories, such as Iraq, Egypt and Sudan etc, for the upstream countries to exploit them politically and economically to achieve their strategic goals, international reports indicated the possibility of a shortage in water resources by the year 2025 in the regions of the Middle East, including Iraq, and although Iraq is rich in water resources until a few decades ago, however, as a result of climatic changes, the increase in water consumption, and what increased these challenges, the upstream countries built dams and irrigation projects on the two rivers (Tigris and Euphrates), all of which led to the exacerbation of the water deficit problem and the deterioration of its quality.

Therefore, maximum efforts must be focused on building and advancing scientific and service institutions to solve problems of Pollution and waste of water resources, such as building dams on rivers and building water harvesting dams while rationalizing water consumption for all purposes and resolving outstanding problems with upstream countries diplomatically with establishing strong economic relations (AL-SARDAR; AL-SAFFAWI, 2019; SALEH et al. 2020; EWAID et al., 2019).

Potable groundwater ranges around 72% of the total drinking water resources in the world (KHEDIDJA et al, 2023). However, it often contains relatively high concentrations of salts, calcium ions, magnesium, sulfates, etc., which makes it hard as a result of the dissolution of some water-soluble compounds, in addition to the salts transferred to it from civil, agricultural and animal activities, in addition to the increase in population gatherings around the areas of the wells. All this led to Increasing water pollution problems and becoming a threat to public health, especially water consumers (AL-MASHHADANY, 2021).

The main problem in Iraq is the presence of salinity in groundwater as a result of geochemical interactions that occur in the geological layers in addition to human activities that can penetrate the ground through permeable layers that increase water pollution problems (EHAB et al., 2020), so it must be followed up the causes of lack of safe water, pollution control, and the use of modern technologies to determine the quality of drinking water (PATIL et al., 2020).

Globally, the pressure on freshwater has increased, as groundwater has emerged as a crucial issue for cities and villages around the world, as reports show that nearly a third of the world's population uses groundwater for drinking as a main source of water supply in many countries, for example, Jordan provides groundwater %(60) of the total supply for different uses, and that its overuse will lead to creating problems in the quantity and quality of groundwater and deteriorating its quality, so the assessment of groundwater quality must be monitored and followed up as a vital step for the effective management of water resources (ABBASNIA et al., 2019; IBRAHIM, 2019; VERMA et al., 2020).

Studies have shown that more than a third of the population of developing countries lack water suitable for human use, which causes more than 875 million cases of diarrhea annually (AL-SHANONA et al., 2020). The high incidence of dehydration results from diarrhea, which may be caused by high sulfate levels in drinking water and microbial contamination. On the other hand, many studies indicate that increased sodium chloride may enhance the risk of cancer resulting from other causes, giving water an unpalatable taste. Nitrates at high levels in drinking water cause many health problems for humans and animals, such as stomach cancer, colon and rectum, thyroid disorders and cancer, brain tumors, etc. These damages are not due to the nitrate ions but rather their microbiological reduction under the tongue to nitrite ions that interact with amines and amides. Various N-nitroso compounds (NOC) in the stomach are carcinogenic and mutagenic (AL-SAFFAWI; AL-MOLAA, 2018).

Therefore, there was an urgent need to improve the management of water resources and find effective solutions to address and mitigate the water deficit, such as rationalizing consumption, using the main principles of integrated and comprehensive management of water resources and other solutions that require only willpower and moving away from courtesy and hard work, since the water problem is an internal problem to the degree. The basis (EWAID et al., 2019: RAHI et al., 2019). Therefore, the current study came to assess the groundwater quality of Tal Abta district and some of its affiliated villages, as it is one of the areas in which qualitative studies have yet to be conducted.

2. MATERIAL AND METHODS

2.1. General description of Tal Abta district

The current study included the Tal Abta district and nine affiliated villages. It is administratively affiliated to the Hatra district, 50 km from the city and 73 km southwest of Mosul. Its economy depends on exploiting its lands for agriculture and livestock and poultry breeding. The district's center is bordered by the valley known as Wadi Tharthar. From the north and east, which is dry most of the seasons of the year except for the rainy season, and in recent decades, the drought problem began to appear frequently in the region due to the lack of rain and irresponsible practices such as overgrazing with high temperatures, which led to soil deterioration and desertification, which was reflected in the vegetation cover (AATYA et al., 2021; NAJEEB; SAEED, 2022)

2.2. Geology of Tal Abta District

The study area consists of the Fatha Formation, which dates back to the Middle Miocene, which is spread in the region and contains salt rocks (Halite), gypsum ($CaSO_4.2H_2O$) and anhydrite ($CaSO_4$) in addition to limestone, clay, and sand rocks. and alluvial, and the Injana Formation dating back to the Upper Miocene era, consisting of periodic sequences of sandstone, alluvial and mudstone, where the mudstone constitutes the largest proportion of the deposits of this formation, As well as Quaternary Deposits, which includes deposits of graded gravel, clayey, sandy and Celtic rocks (AL-HUSSEIN et al., 2023; SHEHAB; YOUNIS, 2022).

2.3. Methodology

10 wells were randomly identified in Tal Abta district, whose characteristics are shown in Table 1 and Figure 2, to collect water samples from July to December 2022 AD (ten replicates for each well), where the water pump for the well was operated for some time. Five minutes later, the selected aqueous sample was taken using clean polyethylene terephthalate bottles and washed with sample water several times before filling it.

Table 1. Characteristics of the sites of the wells under study in the district of Tal Abta and some of its affiliated villages.
Tabela 1. Características dos locais dos poços em estudo no distrito de Tal Abta e algumas das suas aldeias afiliadas.

		Latitude (E)	Longitude (N)	Depth (m)	Uses
St1	Muwailehat Aziz village	42°34'28"	36°03'37"	27	For cleaning, washing clothes dishes, showering and cooking
St2	Northern Turkmen village	42°37'12"	35°58'48"	36	
St3	Southern Tell Faris village	42°34'41"	35°58'39"	26	
St4	Hazimeh Al-Bosalem vill.	42°30'50"	35°58'09"	40	
St5	Tal-Abta district center	42°33'41"	35°56'50"	40	
St6	Southern Turkmen village	42°37'40"	35°55'04"	60	
St7	Ashwa village	42°21'16"	36°00'30"	36	
St8	Khalif Al-Saleh village	42°32'35"	35°57'04"	42	
St9	Abta village south	42°35'56"	35°53'30"	33	
St10	Hajaf village	42°28'40"	35°52'46"	35	

As for bacteriological examinations, pre-sterilized glass vials were used with autoclaves for 15 minutes at a pressure of 1.5 pounds/inch and a temperature of 121 Cº; the samples were kept in a refrigerated box and away from light until reaching the environment and pollution laboratory in the College of Education for Pure Sciences, to conduct physical, chemical and bacteriological tests for water samples based on international standard methods (APHA, 1998; 2017).

Figure 1. A satellite view of the site for collecting water samples from the Tell Abta district.
Figura 1. Vista de satélite dos locais de recolha de amostras de água do distrito de Tell Abta.

2.4. Estimation of the water quality index

The weighted sub-index model was applied to eleven important characteristics compared to the global standard limits for drinking water (WHO 2017) using the following equations (CHEBET et al., 2020; SUNITHA; RADDY, 2022; ANANG et al., 2023):

$$K = \frac{1}{\sum 1/Sti} \quad (01)$$

$$Wti = K/Sti \quad (02)$$

$$Qri = \frac{Cvi}{Sti} \times 100 \quad (03)$$

$$Subi = Wti * Qri \quad (04)$$

Table 2. The global determinants of drinking water (Sti) and the relative weight values for each parameter (Wti).
Tabela 2. Determinantes globais da água potável (Sti) e os valores dos pesos relativos de cada parâmetro (Wti).

Parameter	Sti	Rwi
TC	25	0.052495
pH	8.5	0.154397
EC25	1400	0.000937
T.A.	200	0.006562
T. H.	500	0.002625
Na	200	0.006562
Cl	250	0.005249
SO4	400	0.003281
PO4	2.15	0.610407
NO3	50	0.026247
TPC	10	0.131237
∑		1.000000

$$WQI = \sum Subi \quad (05)$$

where: K: proportionality constant; Sti: standard limits for each parameter; Wti: weight value for each trait as shown in Table 2; Qri: quality rating for each parameter; Cvi: measured concentration of the parameter; Subi: sub-index for each parameter.

After finding a value WQI (water quality) is evaluated into five categories as follows (Issa; Alrawi, 2018): 0.0-25: excellent quality water; 26-50: good water; 51-75: poor quality water; 76 -100: water of very poor quality; ≥ 100: unsuitable water (Unfit).

3. RESULTS AND DISCUSSION

The results ruled in Table 3 indicate that all studied samples are of the category (Very poor quality to Unfit quality) for drinking and civil uses due to the high WQI values that ranged between (73.5 - 1538); this deterioration in water quality came as a result of the high values of most of the parameters that were studied, especially the total number of bacteria TPC, electrical conductivity EC, total hardness T.H, sodium ions, chloride and sulfate, which negatively affected the values of the sub-index (Subi), so that most of these parameters exceeded the permissible limits for drinking and household uses according to the World Health Organization – WHO (2017), (TAHER; SAEED, 2023)

As shown in Table 4 indicates that the studied water temperature is low fluctuation, with rates ranging between (22.1 ± 074 to 22.8 ± 1.03) ˚C, which is attributed to the fact that the wells are deep, and this phenomenon was confirmed by (TALAT et al., 2019; JAAFER; AL-SAFFAWI, 2020; AL-HUSSEIN et al., 2023).

The same is true for the pH, with rates ranging from 0.22 to 7.38 ± 0.23 ± 7.1. This decrease in fluctuation is due to the phenomenon of Acid Neutralization Capacity (ANC) of Iraqi waters and soils rich in carbonate salts. Fortunately, this prevents deterioration in water quality due to its buffering effect for pH and reducing extremes in the values, which confirms that the relatively high values of total alkalinity (caused only by bicarbonate ions), which amounted to (340) ppm at the well (St2).

Table 3. Results of the quality rating (Qri), Sub-index (Subi) and (WQI) values of the studied area.
Tabela 3. Resultados dos valores de classificação de qualidade (Qri), Subíndice (Subi) e (IQA) da área estudada.

Parameters \ Sites		1	2	3	4	5	6	7	8	9	10
TC	Qri	90.40	91.20	90.40	88.40	89.60	90.40	89.6	90.4	88.8	88.8
	Subi	4.746	4.788	4.746	4,641	4.704	4.746	4.704	4.746	4.662	4.662
pH	Qri	83.65	84.90	85.18	86.24	87.60	86.40	87.4	90.1	86.59	86.82
	Subi	12.91	13.12	13.15	13.31	13.53	13.33	13.50	13.91	13.37	13.41
EC_{25}	Qri	222.3	212.1	217.6	288.1	229.4	265.3	241.6	262.3	134.7	223.8
	Subi	0.208	0.199	0.204	0.270	0.215	0.249	0.226	0.246	0.126	0.210
T.A.	Qri	45.40	59.60	48.80	45.60	48.20	37.60	38.0	42.2	52.6	51.0
	Subi	0.298	0.391	0.320	0.299	0.316	0.247	0.249	0.277	0.345	0.335
T.H.	Qri	441.2	504.0	471.6	588.0	345.6	532.8	495.2	642.4	372.4	437.2
	Subi	1.158	1.323	1,238	1,543	0.907	1.398	1.300	1.686	0.977	1.148
Na	Qri	345.0	334.0	318.5	435.0	352.0	408.5	523.0	416.5	101	308.5
	Subi	2.264	2.192	2.090	2.854	2.310	2.681	3.432	2.733	0.663	2.024
Cl	Qri	341.2	337.4	246.0	721.3	262.6	566.6	916.3	750.3	62.48	339.7
	Subi	1.791	1.771	1.291	3.787	1.379	2.975	4.810	3.939	0.328	1.783
SO_4	Qri	360.5	363.3	358.0	381.0	396.5	391.0	417.5	344.5	337	347
	Subi	1.183	1.192	1.175	1.250	1.301	1.283	1.370	1.130	1.106	1.138
PO_4	Qri	29.30	20.50	27.91	23.72	27.90	23.70	30.2	18.6	104.7	24.65
	Subi	17.89	12.49	17.04	14.48	17.04	14.48	18.45	11.36	63.88	15.05
NO_3	Qri	24.96	25.00	24.96	25.04	24.80	25.20	24.9	25.1	24.74	24.84
	Subi	0.655	0.657	0.655	0.657	0.652	0.660	0.654	0.659	0.649	0.652
TPC	Qri	7600	5720	7870	8710	7930	11400	8520	250.0	8470	7450
	Subi	997.4	750.7	1033	1143	1041	1496	1118	32.81	112	977.7
	Value	1041	788.8	1075	1186	1083	1538	1167	73.5	1198	1018
	Status	Unfit	Unfit	Unfit	Unfit	Unfit	Unfit	Unfit	V.P	Unfit	Unfit

V.P.: Very Poor Quality.

On the other hand, the dissolution of CO_2 gas, whether atmospheric or resulting from the biodegradation processes of organic matter in the soil, in rainwater filtered to the depths to interact with limestone rocks or the dolomite to form bicarbonate compounds that are well soluble in water, as in the equations indicated by (AL-SOYFFE et al., 2022; AL-SAFFAWI et al., 2020):

$$[CH_2O] + O_2 \xrightarrow{\text{Oxic Bacteria}} CO_2 + H_2O$$

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

$$2H_2CO_3 + CaMgCO_3 \longrightarrow Ca(HCO_3)2 + Mg(HCO_3)2$$

It is also noted from the same table that salinity levels increased to fluctuate between (1754 to 5994) uS $cm^{-}1$, with a mean and standard deviation between (1886 ±170 to 4033 ±1045) uS cm^{-1}, this increase in values is due to the passage of water through the formation of the hole containing evaporite salts, gypsum, anhydrite, and halite rocks (AL-SAFFAWI et al., 2020; AL-MASHHDANY et al., 2020). These results were observed by Al-Saffawi when he studied the groundwater of the village of Al-Kunsiyyah, Tal Afar district, west of Mosul, which amounted to (5500) uS cm^{-1}, as indicated by (Al-Saffawi et al, 2020). For the same reasons, the concentrations of total hardness, sodium ions, chloride and sulfate increased to reach (2980, 1148, 3418 and 2130) ppm, consecutively (St2).

As for phosphate ions, they were within the permissible limits for drinking, as they did not exceed (0.319) mg. This decrease is attributed to its ability to adsorb on the surfaces of colloidal particles, as well as its deposition in the form of calcium phosphate, as in the equation indicated by (QASEEM et al., 2022; AL-SALLAL, 2023):

$$2PO_4^{-3} + 3Ca^{+2} \longrightarrow Ca_3(PO_4)_2$$

Regarding microbial contamination, it is noted that the total number of bacteria and fecal coliform bacteria increased to reach (1140 ± 254) x 10 3 cells. ml and (424 ± 316) x 102 cells. 100 ml, consecutively. This increase in the levels of bacterial contamination came from the fact that the studied wells are of the open type, which facilitates the transfer of animal waste to the water of the wells. Figure 2 shows the results of the positive and negative (MPN) test in the medium of MacConky broth, and the confirmatory test for the growth of *E. coli* bacteria in the medium of Eosin Methylene Blue (EMB); these results are higher than the results obtained by Al-Hussein et al. (2023) when they studied water subterranean area of Wanh district, where the total number of bacteria did not exceed 9.36×10^3 cells ml^{-1}.

About the results of the statistical analysis of the correlation coefficient (Peterson test), Table (4) indicates that there is a significant correlation between electrical conductivity, sodium and chloride ions at the probability level ($P \geq 0.01$) and with the total hardness at the probability level ($P \geq 0.05$), as well as the significant correlation between Sodium ions and sulfate, in addition to between the total hardness and chloride ions at the level of probability ($P \geq 0.05$). Finally, a significant correlation between sodium and chloride ions at (P ≥ 0.01), which indicates the possibility of groundwater passing through the halite rocks during its movement in the geological formations (KHATTAB et al., 2023).

Table 4. The upper and lower limits, mean and standard deviation of the results of the Groundwater analysis of Tal Abta sub-district (ppm).
Tabela 4. Limites superiores, inferiores, média e desvio padrão dos resultados da análise das águas subterrâneas do subdistrito de Tal Abta (ppm).

Sites	Param.	T°C	pH	EC	T.A	T.H	$SO_4^{=}$	Cl^-	Na^+	PO_4	TPC*	F.C**
1	*Max*	24.0	7.40	3555	124	2740	1696	1657	1008	0.102	869	460
	Mini	22.0	6.70	2442	76.0	1420	1187	552	496	0.026	637	20.0
	Mean	22.6	7.11	3112	111	2206	1442	853	690	0.063	760	98.2
	± *Sd*	0.97	0.22	363	13.5	343.6	211	392	144	0.025	87.9	132
2	*Max*	24.0	7.60	4523	340	2240	2130	3418	1148	0.095	619	0.90
	Mini	22.0	7.00	2317	76.0	1281	821	371	292	0.013	560	0.03
	Mean	22.8	7.22	2969	146	2086	1453	843	668	0.044	572	0.21
	± *Sd*	1.03	0.18	584	74.7	311.4	399	916	306	0.027	17.2	0.26
3	*Max*	24.0	7.60	3365	124	2980	1687	990	780	0.130	905	210
	Mini	22.0	7.00	3042	68.0	1480	1062	409	544	0.033	620	ND
	Mean	22.6	7.24	3047	119	2358	1432	615	637	0.060	787	126
	± *Sd*	0.97	0.18	203	15.5	502.2	165	154	73	0.032	95.7	34.3
4	*Max*	24.0	7.70	5994	104	3480	1838	2057	996	0.096	1042	460
	Mini	21.0	7.10	3203	80.0	1480	1187	1362	776	0.021	709	ND
	Mean	22.1	7.33	4033	111	2940	1524	1803	870	0.051	871	250
	± *Sd*	0.74	0.16	1045	8.70	12.0	194	241	71	0.024	125	146
5	*Max*	24.0	7.70	3950	120	2040	1977	687	788	0.109	967	900
	Mini	20.0	7.20	2738	68.0	1020	1311	409	484	0.027	635	240
	Mean	22.4	7.45	3211	118	1728	1586	566	704	0.060	793	424
	± *Sd*	1.26	0.14	466	16.3	301.3	190	104	104	0.030	122	220
6	*Max*	24.0	7.50	4860	112	3480	1946	3275	1040	0.088	1611	700
	Mini	20.0	7.10	2989	56.0	1680	1139	866	648	0.015	796	110
	Mean	22.6	7.34	3714	91.8	2664	1564	1417	817	0.051	1140	252
	± *Sd*	1.35	0.13	646	16.1	516.2	277	678	166	0.023	254	184
7	*Max*	24.0	7.70	3999	88.0	2980	1950	2990	1276	0.271	1078	900
	Mini	20.0	7.20	2410	56.0	1060	1297	924	668	0.016	662	ND
	Mean	22.4	7.43	3382	92.7	2476	1670	2291	1046	0.065	852	340
	± *Sd*	1.26	0.16	629	8.80	542.7	254	781	185	0.074	139	316
8	*Max*	24.0	9.20	3928	112	4160	1828	2295	1016	0.127	55.0	11.0
	Mini	20.0	7.10	3459	24.0	1740	568	409	648	0.004	14.0	0.04
	Mean	22.6	7.66	3672	111	3212	1378	1876	833	0.040	25	3.21
	± *Sd*	1.35	0.72	177	26.6	665.7	336	545	128	0.040	14.8	3.39
9	*Max*	24.0	7.90	2166	132	2900	1559	276	252	0.319	1038	700
	Mini	20.0	7.00	1754	76.0	1060	986	86	148	0.142	759	110
	Mean	22.2	7.36	1886	129	1186	1348	156	202	0.225	847	304
	± *Sd*	1.48	0.32	170	13.3	468.8	262	55.8	37	0.053	88.7	220
10	*Max*	24.0	7.70	3339	116	2700	1822	1152	820	0.089	994	930
	Mini	20.0	7.10	3002	76.0	1360	1041	800	360	0.008	180	110
	Mean	22.2	7.38	3133	125	2186	1388	849	617	0.053	745	263
	± *Sd*	1.14	023	106	18.6	407	227	210	136	0.029	213	272

*$\times 10^3$ cell ml^{-1}; **$\times 10^2$cell 100 ml^{-1}.

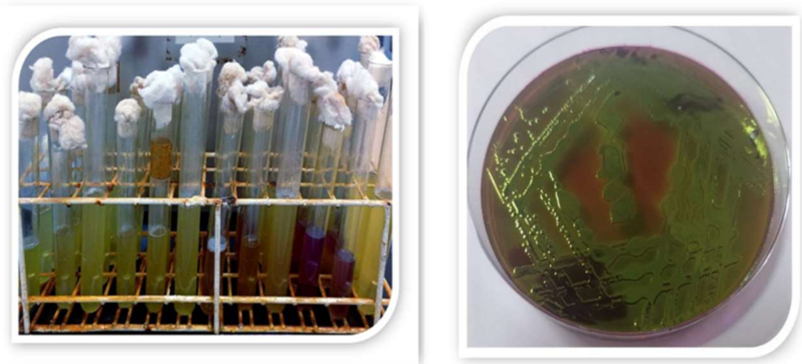

Figure 2. Test results for the positive and negative tubes in the liquid media of MacConkey Broth and the bacteria *E. coli* growing on Eosin methylene blue (EMB) media.
Figura 2. Resultados do teste para os tubos positivos e negativos no meio líquido do caldo MacConkey e para a bactéria *E. coli* crescendo no meio Eosina azul de metileno (EMB).

Table 4. Statistical analysis results of the Pearson Correlation test for the studied parameters.
Tabela 4. Resultados da análise estatística do teste de Correlação de Pearson para os parâmetros estudados.

Param.	ToC	pH	EC_{25}	T.AIK	T.H	SO_4	Cl	Na	TPC	F.C
TC	1.0									
pH	.573-	1.0								
EC_{25}	.063	.167	1.0							
T.AIK	.089	.424-	.564-	1.0						
T.H	.084	.063-	.683*	.312-	1.0					
SO_4	.004	.154	.487	.613-	.280	1.0				
Cl	.011-	.229	.766**	.663-*	.662*	.525	1.0			
Na	.185	.080	.871**	.643-*	.599	.715*	.882**	1.0		
T.P.C	.302-	.106	.075-	.301-	.136	.469	.179-	.067-	1.0	
F.C	.418-	.153	.134-	.161	.411-	.200-	.391-	.242-	.186	1.0

* Significant correlation at the level of ($P \geq 0.05$), ** at the level of ($P \geq 0.01$)

5. CONCLUSIONS

Groundwater was characterized by high levels of electrical conductivity, total hardness, sodium ions, chlorides and sulfates, which was confirmed by the significant Pearson correlation coefficient at the level of probability (P≥ 0.01 and 0.05), as well as the presence of bacterial contamination beyond the recommended limits for drinking.

All WQI values were high to classify the water as poor or unfit for drinking and domestic use.

Therefore, we recommend periodic monitoring and testing of these water sources, with the use of some simple and easy techniques to improve water quality, such as removing salts and reducing the number of bacteria, to make them suitable for use when needed, such as the technique of slow freezing and thawing using a home refrigerator (AL-HAMDANI; AL-SAFFAWI, 2018).

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