Environmental Research and Technology
https://dergipark.org.tr/en/pub/ert
DOI: https://10.35208/ert.1484374

Environmental Research & Technology

Research Article

Water quality and spatial distribution of wells in the Eastern Side of Nineveh Governorate – Iraq

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ARTICLE INFO

Article history
Received: 16 May 2024
Revised: 26 Jul 2024
Accepted: 04 Aug 2024

Key words:
WQI, water assessment, water quality, groundwater, nineveh.

ABSTRACT

The quality of groundwater in the studied area are related to the reservoir rock types, which are mainly represented by the dolomitic limestone of Pila Spi Formation, the limestone and gypsum of Fat'ha Formation, the sandstone of Injana Formation, the sandstone of Muqdadiya Formation. These rocks exposed at the feet of Bashiqa and Ain Al-Safra mountains. The ability of minerals in these rocks to dissolve under weathering conditions also affects water quality.
The water quality index (WQI) was calculated to determine its suitability for domestic uses based on the physical (pH, E.C, T.D.S and T.H) and chemical (Ca^{2+}, Mg^{2+}, N^{a+}, K^{+}, HCO_{3-}, SO_4^{2-}, Cl^- and NO_{3-}) specifications of forty-one wells. The distribution of wells was determined according to their specifications. In general, the study area was divided from north to south into six regions with QWI; excellent water, good water, unsuitable water, poor water quality, while the area adjacent to Ain Al-Sufra Mountain has a good water, and the area located to the southwest towards the Tigris River is very poor water.
The SAR ratio (< 10) and the sodium percentage (SSP% < 75%) indicated a low soda content, the amount of RSBC < 1.25 meq L-, the Kelly ratio (KR < 1) and permeability index (PI < 75%) have no effect on the soil properties and no negative impacts on the quality of irrigation water, thus the well water source is suitable for irrigating most crops and all types of soil.

Cite this article as: Al-Youzbakey KT, Sulaiman AM. Water quality and spatial distribution of wells in the Eastern Side of Nineveh Governorate – Iraq. Environ Res Tec 2025;8(2)234-244.

INTRODUCTION

Groundwater is an important resource, especially in areas where water resources do not meet the requirements of life. Therefore, population centers in areas far from rivers are linked to the quantity and quality of groundwater available. The study area represents a large part of the eastern part of Nineveh Governorate, which is dotted with small cities and villages with population and agricultural activity.

Study area

Nineveh Governorate is located in the northern part of Iraq, and the study area is located east of the Tigris River within the eastern side of Nineveh Governorate between (36°00'00' - 36°45'00") to the north and (42°45'00" - 43°45'00" to the east, The area of the study area is 4,110 km2, bordered to the north by Mount Al-Qosh, Mount Dehqan, Mount Qand, and Mount Bashiqa to the northeast, Mount Ain Al-Safra to the east, the Khazar River and the Great Zab River to the south-east, and the Tigris River to the southwest and west, (Fig. 1).

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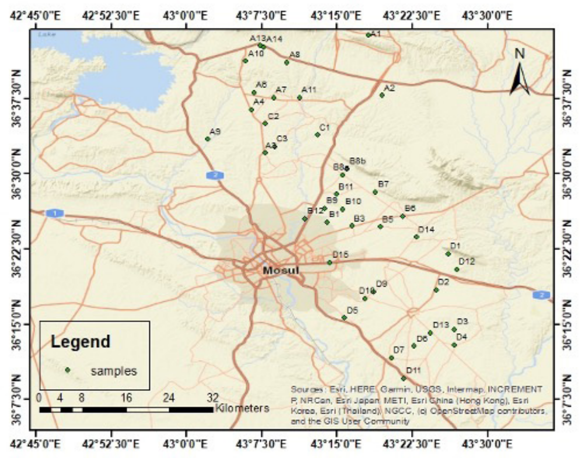

Figure 1. The distribution of the wells in the studied area.

The most important structural features in the region are the presence of mountains surrounding the region from the eastern side, represented by the Qand Mountain (about 450 m.a.s.l.), which represents the Qand anticline, which is located in the northeastern side and its axis is northwest-southeast. Its length is 22.5 km and its width ranges from (2.5-4.5) km. Then Mount Bashiqa (657 m.a.s.l.), which represents the Fadhiliyah and Bashiqa anticlines, which follow in the same direction northwest - southwest, with a length of 15 km and 10 km, respectively, with a width of 2 km. And Ain Al-Safra Mountain (68 m.a.s.l.) represents Ain Al-Safra Anticline, which is located to the southeast of Mount Bashiqa and its axis is northwest-southeast, with a length of 8 km and a width of 3.5 km.

Geological setting

Rocks belong to several formations are exposed in the region, the oldest of which is the Pila Spi Formation (Middle-Upper Eocene), which composed of hard, stratified dolomitized limestone, represent the Bashiqa and Ain Al-Safra Mountains, and occupy the core of these folds [1]. The Fatha Formation (Middle Miocene) finds appear at the feet of the Bashiqa and Ain Al-Safra mountains in the form of a belt surrounding them [2]. The Fatha Formation includes several depositional cycles consisting of successions of green marl, limestone, clay and gypsum-anhydrite rocks [3, 4]. The Ingana Formation (Upper Miocene) follows the Fatha Formation and appears as discontinuous ridges around the Bashiqa-Fadhiliya anticlines and the Ain Al-Safra anticline [5], while its rocks represent Mount Qand [6]. The Injana Formation consists of sedimentary cycles of sandstone, siltstone, and mudstone [1]. It is followed by the Muqdadiya Formation (Pliocene), consisting of a succession of sandstone, shale, and siltstone, with layers of sandstone containing gravel [1, 2]. Bai Hassan Formation (Pliocene – Pleistocene), it is considered the newest formation in the region, consists of alternation of thick conglomerate and reddish-brown claystone, with thin gray sandstone [1, 5].

The above formations are covered by Quaternary deposits (Pleistocene), and are represented by river terrace deposits consisting of conglomerates containing sand and alluvial lenses, slope deposits, floodplain deposits, [5, 7], and alluvial fans containing rock fragment components. Some of them are bound with calcareous cement [1]. These sediments generally represent the products of weathering of the above formations that are exposed to weathering and erosion activities [2]. As for the upper layer of soil, it is of the type of aerated and riverine transported soil. It has a fine texture, a brown color, and contains a high percentage of sulphates and carbonates, resulting from the weathering of evaporite rocks and limestone belonging to the Fatha Formation mainly [8, 9].

The region is generally characterized by its varying terrain, ranging from flat to slightly sloping and undulating towards the southwest, and its average elevation ranges between 300-400 m.a.s.l. The region generally descends from mountainous areas towards the south and southwest towards the Tigris River, and the region is interspersed with a group of main and subsidiary valleys towards the south and southwest towards the Tigris River and the Greater Zab River, [2, 8, 9, 10]. The region also slopes topographically from the city of Mosul in a northeasterly direction, and thus the study area forms a wide, low-lying depression represented midway between the city of Mosul and the mountains of Bashiqa and Qand, [11]. This depression represents the area where rainfall in the region reaches 375-425 mm on average for the period 2010-2020, according to data from the Iraqi General Authority for Meteorology, [12], that feeds it with groundwater, through the many parallel valleys extending from the mountainous areas towards the region, [13]. The valleys also transport the products of weathering and erosion from the high areas, which often represent outcrops of geological formations in the region, and these sediments are spread to cover the region [1].

Al-Youzbakey and Eclimes, [14] pointed out that the topography of the region has contributed to influencing the hydrochemical characteristics of the water. Shallow wells in the Al-Hamdaniya area, as the phenomena of seepage and rainwater infiltration reflected the activity of dissolution processes for the rock components present in the resent sediments derived from the rocks of the region and in the soil, which are mainly composed of evaporites and marl, in addition to the carbonate components.

Al-Youzbakey and Sulaiman [13] showed that the study area is generally characterized by two types of underground wells. The first type is characterized by being shallow, shallow wells that represent underground reservoirs within the sandstone layer belonging to the Injana Formation, with a low content of salts. The other type is with deep wells that reach underground reservoirs within the Fatha Formation, which is a network of dissolution channels within the gypsum rocks, and therefore its sulfate content is high, which makes the use of water limited for irrigation purposes and for specific types of crops that tolerate high sulfur concentrations.

The results of Al-Saffawi et al [15] study indicated that the water quality index values in the wells of the Hamdaniya region ranged between (33.0 to 282) due to the different geological formations through which the water passes, as 45% of the water samples were of the invalid category, and 25% from the category of poor-quality water. The remaining 30% is water suitable for watering livestock and poultry.

Al-Sayegh and Khaled [9] explain that most of the soils of the study area are calcareous soils, as the highest value was recorded in the fifth horizon of the Tal Kayf soil in the Al-Qosh Plain (450.8 g.kg-1), while the lowest values were recorded in the Bashiqa soil (268.4 gm.kg-1). As for the distribution of calcium carbonate in the soil, the results showed some increases in the calcium carbonate content with depth.

Najeeb and Saeed [16] calculated the water quality factor for selected wells in the Al-Hamdaniya District and found that the water quality is not suitable for drinking. They pointed out that the phenomenon of drought and declining rainfall are among the most prominent factors affecting water quality in the region.

The study aims to determine the distribution of wells according to their quality for the purpose of determining the different areas of their use or non-use due to their quality.

METHODOLOGY

Forty-one wells were selected to cover the study area: A1 (Taq Harb), A2 (Mahad complex), A3 (Batnay), A4 (Telskuf), A6 (Dughat), A7 (Sershka), A8 (Shekhka), A9 (Gara Eshaq), A10 (Sharafya), A11 (Alqosh), A12 (Dahqan sagheer), A13 (Zaytoon farm1), A14 (Zaytoon farm2), B1 (Orta Kharab), B3 (Dar Smagh), B5 (Abu Jarbuaa), B6 (Bashiqa cross), B7 (Al-Benit farm), B8a (Al-Fadhelya1), B8b (Al-Fadhelya2), B9 (Bibukhet), B1 (Telyara), B11 (Semaqya), B12 (Abasya), C1 (Rakaba), C2 (Bakufa), C3 (Mar Oraha), D1 (Basakhra), D2 (Karamleas), D3 (kabarly), D4 (Khraba Sultan), D5 (Yarghanty), D6 (Kahreez), D7 (Omar Khan), D9 (Manara Shabak), D10 (Ali Rash), D11 (Tel Aakub), D12 (Bazkertan), D13 (Plawat), D14 (Teas Kharab), D15 (Kogjaly), (Fig. 1).

The temperature, acid function, and electrical conductivity were measured in the field, using a portable Ec type (hold / 3meter), and laboratory analyzes were conducted according to standard methods [17]. Total hardness, calcium and magnesium were measured by elution with EDTA, and chloride by elution with HCl. The flame spectrophotometer method was used with a JENWAY PEP7 type flame spectrophotometer to measure sodium and potassium. Colorimetric methods were used to measure sulphates and nitrates using a device (UV- Spectrophoto-meter type - OGAWA, OSK 7724). Total soluble salts were measured laboratory by the traditional method [18].

The ionic balance was used between the concentrations of cations and anions in (meq L-1) to achieve analytical accuracy according to equation (1), [19].

Ionic balance (%) = ($\sum$cat. - $\sum$ani.) / ($\sum$cat. + $\sum$ani.) X 100 .... (1)

The Water Quality Index (WQI) represents the conversion of all data related to water quality into a mathematical number that expresses the level of water quality [20, 21, 22] to determine the suitability of well water in the two study areas. For drinking and civilian uses, the water quality index (WQI) was calculated using all of the above parameters and based on World Health Organization standards (Table 1) [23], and according to equation (2) and table (2). [24]:

IWQI=$\sum$Qi*Wi/$\sum$Wi..(2)

Qi=100×(Vm-Vi)/(Vs-Vi)

Wi=K/Vs

whereas:

Qi = is a measure of the total element quality in the water.

Vm = measured value of water samples (measured analytes)

Vi = the ideal value is zero for most parameters, except pH =7 according to [24].

Vs = standard values of the water quality parameters given by WHO.. [23]

Wi = is the relative unit weight of the element n.

K = is a constant of proportionality, and its value = 1.

The following equations were used to calculate the sodium adsorption rate (SAR), the percentage of sodium (SSP), the amount of carbon remaining in the soil (Residual sodium carbonate, RSBC), the permeability index (PI), the percentage of magnesium (MAR), and the Kelley ratio (KR). All the concentrations are in meq L-:

SAR=Na^+/($\sqrt{}$(Ca^2+Mg^{2+}/2 .... (3)

SSP (Na%) = (Na^++K^+X100)/(Ca^{2+}+Mg^{2+}+Na^+ +K^+)...(4)

RSBC=(CO_3^{2-}+HCO_3^-)-(Ca^{2+}+Mg^{2+})........................ (5)

PI=(Na^++$\sqrt{}$$HCO_3^-$X100)/$Ca^{2+}$+$Mg^{2+}$+$Na^+$)........................ (6)

KR=Na+/(Ca^{2+}+Mg^{2+})..(7)

MAR=Mg^{2+}X100/(Ca^{2+}+Mg^{2+})..(8)

RESULTS AND DISCUSSION

Table (3) shows the physical (pH, E.C., TDS, TH) and chemical (Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, SO_4^{2-}, Cl^- and NO_3^-) specifications that control the water quality of the wells of the study area. The pH values (Minimum-Maximum and Average) for the four groups A, B, C and D were (7.1-8.13, 7.42), (6.94-7.94, 7.34), (7.50-8.00, 7.77) and (7.00-8.10, 7.53). respectively. The TDS values for the four groups were (279-1758, 834), (1060-3440, 1882), (943-1185, 1097) and (255-3316, 1374) mg L-, respectively, and lower values are noted in group A compared to the other groups. This is also reflected in the electrical conductivity values of the four groups (350-

Table 1. The chemical standard specifications (Vs) for drinking water according [23].

pH	EC	TDS	TH	HCO_3^-	SO_4^{2-}	Cl^-	NO_3^-	Ca^{2+}	Mg^{2+}	Na^+	K^+
8.5	1400	1000	500	400	400	250	50	75	50	200	55

1685, 733), (1183-3528, 2068), (2010-2521, 2340) and (340-4443, 1976) µs.cm-, respectively. It is noted that the electrical conductivity values in the group are lower. A compared to other groups, despite the presence of wells with high concentrations of total dissolved salts, either due to a local change in the location of the well, such as a topographical change, an increase in human activity (agricultural and domestic), or a change in the characteristics of the host rocks. The total hardness values reached TH for the four groups (74-2100, 702), (780-2320, 1273), (965-1537, 1221) and (114-1817, 787) mg L-, respectively. Low values are generally observed in groups A and D compared to groups B and C.

The concentrations of calcium for the four groups were (16-661, 167), (168-559, 314), (198-322, 256) and (26-395, 168) mg L-, respectively, and for magnesium in the four groups (11-126, 56), (41-164, 86), (80-178, 116) and (12-208, 86) mg L-, respectively.

Table 2. Water quality scale, according to [24]

WQI values	0-25	26-50	51-75	76-100	>100
Water class	Excellent	Good	Poor	Very poor	Unsuitable

Table 3. The physical and chemical properties of well's water in the studied area.

W. S.	PH	E.C µs.cm-	T.D.S mg L-	T.H mg L-	Ca^{2+} mg L-	Mg2+ mg L-	Na^+ mg L-	K^+ mg L-	HCO_3^- mg L-	SO_4^{2-} mg L-	Cl^- mg L-	NO_3^- mg L-
A1	7.20	510	381	94	19	11	100	4	290	24	35	1
A2	7.40	350	279	98	24	20	28	10	105	83	13	12
A3	7.84	542	524	740	97	86	10	2	438	179	15	1
A4	7.34	579	548	380	54	37	20	2	140	187	10	2
A6	7.40	536	493	520	85	51	15	2	305	141	10	2
A7	7.22	631	605	580	120	24	18	3	249	187	13	6
A8	7.20	490	388	74	16	35	42	9	207	32	19	14
A9	7.30	570	1758	878	144	126	192	11	536	692	97	8
A10	7.10	550	557	195	56	41	27	3	256	91	32	2
A11	7.40	450	1396	980	262	80	41	5	334	744	23	4
A12	7.10	1000	929	487	91	70	125	2	73	530	89	6
A13	7.77	1638	1480	2000	661	68	12	3	134	1835	8	1
A14	8.13	1685	1510	2100	537	78	16	5	312	1321	24	1
Min.	7.1	350	279	74	16	11	10	2	73	24	8	1
Max.	8.13	1685	1758	2100	661	126	192	11	536	1835	97	14
Aver.	7.42	733	834	702	167	56	50	5	260	465	30	5
B1	7.24	3528	3440	1760	490	119	217	3	448	1397	219	41
B3	7.01	2898	2660	1480	492	74	203	2	392	1362	167	28
B5	7.55	3500	3129	2320	559	164	130	2	344	1759	115	28
B6	7.94	1183	1060	780	231	41	9	2	268	384	33	13
B7	6.94	1376	1360	1200	232	70	37	1	376	499	27	3
B8a	7.24	1271	1060	920	252	50	20	1	392	498	31	11
B8b	7.26	1500	1449	1080	277	72	20	2	388	556	23	10
B9	7.31	2048	1860	1380	252	114	10	2	428	623	74	47
B10	7.33	2268	2048	1160	266	87	62	2	412	480	186	47
B11	7.37	1649	1460	1020	240	81	30	1	528	509	74	7
B12	7.50	1523	1180	900	168	74	69	1	512	362	68	8
Min.	6.94	1183	1060	780	168	41	9	1	268	362	23	3

W. S.	PH	E.C µs.cm-	T.D.S mg L-	T.H mg L-	Ca^{2+} mg L-	Mg2+ mg L-	Na^{+} mg L-	K^{+} mg L-	HCO_3^- mg L-	SO_4^{2-} mg L-	Cl^- mg L-	NO_3^- mg L-
Max.	7.94	3528	3440	2320	559	164	217	3	528	1759	219	47
Aver.	7.34	2068	1882	1273	314	86	73	2	408	766	92	22
C1	7.50	2521	1185	965	198	90	210	1	420	162	296	582
C2	7.80	2489	1164	1161	249	80	154	1	473	450	248	144
C3	8.00	2010	943	1537	322	178	94	16	298	1400	50	24
Min.	7.5	2010	943	965	198	80	94	1	298	162	50	24
Max.	8	2521	1185	1537	322	178	210	16	473	1400	296	582
Aver.	7.77	2340	1097	1221	256	116	153	6	397	671	198	250
D1	7.20	1260	716	560	156	41	16	2	207	312	71	1
D2	7.00	4109	2476	1567	285	208	164	3	360	1201	248	1
D3	7.90	810	499	114	26	12	131	2	174	120	71	1
D4	7.70	935	787	786	158	95	382	2	305	936	281	9
D5	7.80	3780	2270	1161	212	153	230	2	332	1105	106	46
D6	7.80	940	3316	971	244	88	674	2	98	1268	738	15
D7	7.50	1390	786	451	90	55	96	2	238	264	71	56
D9	7.30	4042	2350	1331	317	146	64	146	455	768	355	116
D10	7.70	1224	720	414	94	50	6	70	270	192	80	67
D11	7.20	4443	2726	1817	395	171	9	142	220	1297	248	130
D12	7.20	1527	888	679	158	44	4	67	217	336	124	1
D13	7.70	970	562	247	56	26	102	2	216	138	71	25
D14	8.10	340	255	263	67	23	48	1	312	30	27	24
D15	7.30	1895	891	653	100	98	160	1	586	240	125	109
Min.	7	340	255	114	26	12	4	1	98	30	27	1
Max.	8.1	4443	3316	1817	395	208	674	146	586	1297	738	130
Aver.	7.53	1976	1374	787	168	86	149	32	285	586	187	43

Table (3) indicates that the calcium values in the well water of groups A and D are low compared to the rest of the groups, while magnesium is low in group A relative to the rest of the groups. The table also indicates that calcium concentrations are higher than magnesium concentrations, and this is due to the widespread presence of calcium sulphate phases such as gypsum, anhydrite, and calcite, more than the dolomite phase in the soil of the region derived from the erosion of exposed rocks belonging to the Pila Spi and Fat'ha formations.

Sodium and potassium are among the most important ions that make up the group of halides minerals, the most important of which is halite, which consists of sodium chloride and a small percentage of potassium substitution. The mineral halite is found within the group of evaporite rocks in the form of lenses of limited extent and small size, especially in the rocks of the Fatha Formation. It is also found in the form of secondary minerals in the upper part of the soil and on its surface as a result of the continuous dissolution, transport, and sedimentation factors to which the soil is exposed due to rainwater and surface water, especially during rainfall. The sodium concentration for the four groups ranged from (10-192, 50), (9-217, 73), (94-210, 153) and (4-674, 149) mg L-, respectively, and the potassium concentration for the four groups (2-11, 5), (1-3, 2), (1-16, 6) and (1-146, 32) mg L-, respectively. It is noted from Table (3) that the variations in sodium concentrations are due to the varying influence of climate factors, the most important of which are rainfall and a successive increase in temperature. The topography of the region directs surface water towards low-lying locations, which helps water accumulate and then precipitate halite in the event of interruption of rainfall and an increase in temperature. Potassium concentrations reflect agricultural activity that depends on the use of chemical fertilizers, and therefore its concentrations vary according to the soil content of these fertilizers, in addition to the fact that it is an ion with a high ability to dissolve and move from the surrounding areas. Low concentrations of potassium may represent the effect of clay minerals that absorb potassium and lose potassium during the washing and dissolution processes [10].

Bicarbonate is produced from many sources; The most important of which is the dissolution of carbonate minerals in the limestone rocks exposed in the region and belonging to the Pila Spi and Fatha formations, or as a result of the exposure of the carbonate clastic components in the upper part of the soil to the influence of weathering factors, rain, and surface water resulting from them. Carbonate cement materials also contribute to marl rocks and marly limestones that are subject to chemical weathering. The bicarbonate levels for the four groups ranged from (73-536, 260), (268-528, 408), (298-473, 397) and (98-586, 285) mg L-, respectively. The bicarbonate concentrations do not vary significantly due to the similar influence of the rocky outcrops in the studied area, especially along the northeastern and northern parts of the study area, mainly represented by the Ain Safra and Bashiqa mountains, as well as the Alqosh and Dahqan Mountains in the northern and northwestern part of the study area.

Sulphates represent the most concentrated ion in well water in general. This is due to the prevalence of evaporite rocks in the Fatha Formation, which contains partial water in the form of dissolution channels and cavitations due to dissolution. This water is usually in hydraulic contact with groundwater stored in sandstones to form Injana, and therefore the water, with its sulphate content, mixes with underground reservoirs in Injana Formation. On the other hand, the soils derived from the erosion and weathering of exposed rocks of the Pila Spi and Fat'ha formations contain clastic components consisting of carbonate and gypsum minerals. These components are a source of supplying sulphates to rainwater and surface water seeping through the soil. In light of this, the region's well water varies greatly in its sulfate content depending on the effect of the above factors on water quality, as sulfate concentrations range for the four groups (24-1835, 465), (23-219, 766), (162-1400, 671) and (30-1297, 586) mg L-, respectively. It is noted from Table (1) that the sulphate concentration is very high in Group C due to the presence of water within the rocks of the Fatha Formation, and the sulphate concentrations are also high in Group D due to the influence of soil rich in carbonate and gypsum clastic components. Compared to well water in other groups.

The chloride concentration is usually associated with the sodium concentration in the well water of the study area [10] due to their presence mostly in the halite phase, and therefore its source is either from the halite lenses present within the gypsum rocks to form the hole or/and the presence of halite in the form of secondary salts in the upper part of the soil. The chloride concentration for the four groups ranges from (8-97, 30), (23-219, 92), (50-298, 198) and (27-738, 187) mg L-, respectively. These ranges reflect the effect of surface water and rainfall activities on the soil surface that contain different amount of secondary halite [25].

There are many sources of nitrates in well water. Some nitrates come from the atmosphere as a result of dissolution in rainwater and then being fixed in the soil by bacteria, or as a result of agricultural activities such as the use of complex chemical fertilizers or organic fertilizers by farmers or animal husbandry. Therefore, the concentration of nitrates in general is low except for well water located within fields with Agricultural activity and animal husbandry, so nitrate concentrations for the four groups range (1-14, 5), (3-47, 22), (24-582, 250) and (1-130, 43) mg L-, respectively.

It appears from Table (4) that the quality of water in the region's wells varies from excellent to unsuitable. Figure (2) shows the distribution of wells according to their quality. It appears that there are several areas in the north of the study area, where the wells located in the first sector near Mount Qand (in the area located on the northern flank of the Qand anticline) are distinguished by being of the excellent type. This is due to the fact that the groundwater in this

area is found within the sandy sedimentary forms belonging to the Injana Formation with There is little effect of the soil components that contain the products of sandstone erosion, and therefore the well water is of excellent quality. While the wells located to the south of Mount Qand and adjacent to the area representing the southern flank of the Qand anticline and extending south, the wells' water is of good quality and suitable for drinking. As for the wells located to the south of the previous area, their water is characterized by being unsuitable for drinking, and they are wells (C1 - C3). This is due to the fact that the water of these wells is found in reservoir rocks of the evaporite type represented by gypsum-anhydrite rocks belonging to the Fat'ha Formation. The well water in the area between Mount Bashiqa and the city of Mosul, which is located geographically to the south of the previous area, is characterized by the fact that the well water is of poor quality and is not suitable for drinking. The reason is that the water of these wells is found within the rocks of the Muqdadiya Formation and is greatly affected by the seepage of water through the containing soil. On rock pieces of carbonate and gypsum coming from the erosion of the rocks of the Pila Spi Formation and the exposed opening in the southwestern flank of the Bashiqa anticline.

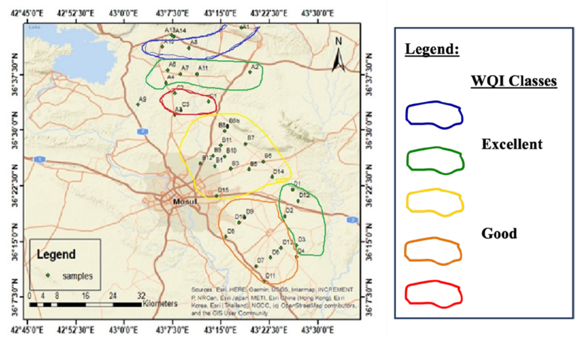

Figure 2. The general spatial distribution map of wells according to WQI.

As for the wells located within the area adjacent to the southwestern wing of the Ain Al-Safra anticline, their water is characterized by being of good quality and suitable for drinking due to the lack of influence of the soil on water quality, while the group of wells located to the southwest of the previous group is distinguished by the fact that the well water is of very poor quality. This is due to the effect of soil derived and transported from the erosion of rocks exposed within the southwestern flank of the Ain Sufra anticline, which contains clastic components of sulphate and carbonate. Therefore, the water seeping through this soil will be rich in sulfate and carbonate ions, which will lead to a significant deterioration in water quality.

Table (5) displays the ionic balance between cations and anions, which reflects the accuracy of the analysis results because the difference between the total cations and anions is generally less than 5% [19]. These values are used to calculate well water parameters for irrigation purposes.

Water quality parameters for irrigation

Nineveh Governorate is characterized by agricultural activity, especially the cultivation of wheat and barley, which depend mainly on rain. Well water, especially with low salinity, can be used for irrigation during periods of declining rainfall or for supplementary irrigation, in addition to being used to irrigate farms that grow trees and other crops.

Well water can be classified according to irrigation parameters [26]. Sodium is one of the most prominent main elements responsible for evaluating well water for irrigation purposes, because it affects soil properties more than other cations. Several parameters are used to evaluate the sodium content of well water and its effect on soil properties, such as the sodium adsorption ratio (SAR). Table (6) shows that the ratio (SAR < 10) indicates a low soda content, and thus the well water source is suitable for irrigating most crops and all types of soil. The percentage of sodium (SSP%) does not exceed 75%, which also indicates the suitability of well water for irrigation. As for the amount of residual sodium bicarbonate, it has no effect on the soil properties because all wells have RSBC values < 1.25. The Kelly ratio and permeability index (KR < 1) and (PI < 75%), respectively, indicate that well water don't have a negative impact on the quality of irrigation water and that they are good - suitable for irrigation.

It should be noted that the waters of some wells located in the northwestern part of the Nineveh plain were classified as a high content of magnesium (MAR > 50%) (Table 6), because the soil prevailing in this part is transport and derived from the dolomitic limestone and dolostone of Pila Spi Formation, and contains fragments of dolomite and dolomitic limestone.

On the other hand, sulfates do not negatively affect plants and soil, but it was noted through field observations and inquiries from farmers that high concentrations of sulfates lead to damage the plant parts, especially in the early stages of growth, in addition to the use of well water with high sulfates leads to salinization of the soil, during several years of irrigation. Therefore, well water with concentrations exceeding 20 epm (960 mg/L) is not suitable for use for irrigation purposes [27], such as wells (A13, A14, B1, B3, B5, C3, D2, D5, D6 and D11).

Table 4. Water quality index (WQI) values and classification for the well's water, according to [24].

Well Symb.	Well name	WQI	Class	Well Symb.	Well name	WQI	Class
A1	Taq Harb	15.09		A9	Gara Eshaq	60.88	
A8	Shekhka	21.70	Excellent	A11	Alqosh	61.33	
A10	Sharafyia	19.80		D4	Khraba sultan	73.21	
B7	Al-benit farm	38.55		D7	Omar kan	53.20	Poor
B8a	Al-Fadhelyia1	48.48		D10	Ali rash	71.96	
A2	Mahad complex	26.43		D14	Teas Kharab	59.20	
A4	Telskuf	27.84		D15	Kogjaly	67.77	
A6	Dughat	36.02		B1	OrtaKharab	98.45	
A7	Sershka	28.14	Good	B3	Dar Smagh	76.61	
A12	Dahqan sagheer	32.28		D2	Karamleas	79.15	Very poor
D1	Basakhra	33.55		D5	Yarghanty	99.54	
D3	kabarly	42.86		D6	Kahreez	93.22	
D12	Bazkertan	45.36		B5	Abu Jarbuaa	122.01	Unsuitable
D13	Plawat	45.40		A13	Zaytoon farm1	110.96	
B6	Bashiqa cross	70.89		A14	Zaytoon farm2	115.58	
B8b	Al-Fadhelyia2	56.27		C1	Rakaba	175.71	
B9	Bibukhet	72.80		C2	Bakufa	105.19	
B10	Telyara	70.27	Poor	C3	Mar Oraha	117.77	
B11	Semaqya	58.98		D9	Manara Shabak	124.52	
B12	Abasyia	56.09		D11	Tel Aakub	134.95	
A3	Batnay	61.24					

Table 5. The ionic balance for the water of the studied wells (meq L-).

	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Total	HCO_3^-	SO_4^{2-}	Cl^-	NO_3^-	Total	Δ
A1	0.95	0.90	4.35	0.10	6.30	4.75	0.50	0.99	0.02	6.26	0.04
A2	1.20	1.64	1.22	0.26	4.32	1.72	1.73	0.37	0.19	4.01	0.31
A3	4.84	7.07	0.43	0.05	12.40	7.18	3.73	0.42	0.02	11.34	1.06
A4	2.69	3.04	0.87	0.05	6.66	2.29	3.89	0.28	0.03	6.50	0.16
A6	4.24	4.19	0.65	0.05	9.14	5.00	2.94	0.28	0.03	8.25	0.89
A7	5.99	1.97	0.78	0.08	8.82	4.08	3.89	0.37	0.10	8.44	0.38
A8	0.80	2.88	1.83	0.23	5.73	3.39	0.67	0.54	0.23	4.82	0.91
A9	7.19	10.36	8.35	0.28	26.18	8.79	14.40	2.74	0.13	26.05	0.13
A10	2.79	3.37	1.17	0.08	7.42	4.20	1.89	0.90	0.03	7.02	0.4
A11	13.07	6.58	1.78	0.13	21.56	5.47	15.49	0.65	0.06	21.67	0.11
A12	4.54	5.76	5.43	0.05	15.78	1.20	11.03	2.51	0.10	14.84	0.94
A13	32.98	5.59	0.52	0.08	39.17	2.20	38.20	0.23	0.02	40.64	1.47
A14	26.80	6.41	0.70	0.13	34.03	5.11	27.50	0.68	0.02	33.30	0.73
B1	24.45	9.79	9.43	0.08	43.75	7.34	29.08	6.18	0.66	43.26	0.49
B3	24.55	6.09	8.83	0.05	39.51	6.43	28.35	4.71	0.45	39.94	0.43
B5	27.89	13.49	5.65	0.05	47.08	5.64	36.62	3.24	0.45	45.95	1.13
B6	11.53	3.37	0.39	0.05	15.34	4.39	7.99	0.93	0.21	13.53	1.81
B7	11.58	5.76	1.61	0.03	18.97	6.16	10.39	0.76	0.05	17.36	1.61
B8a	12.57	4.11	0.87	0.03	17.58	6.43	10.37	0.87	0.18	17.84	0.26
B8b	13.82	5.92	0.87	0.05	20.66	6.36	11.57	0.65	0.16	18.74	1.92
B9	12.57	9.38	0.43	0.05	22.44	7.02	12.97	2.09	0.76	22.83	0.39
B10	13.27	7.15	2.70	0.05	23.17	6.75	9.99	5.25	0.76	22.75	0.42
B11	11.98	6.66	1.30	0.03	19.97	8.65	10.60	2.09	0.11	21.45	1.48
B12	8.38	6.09	3.00	0.03	17.49	8.39	7.54	1.92	0.13	17.97	0.48
C1	9.88	7.40	9.13	0.03	26.44	6.88	3.37	8.35	9.39	27.99	1.55
C2	12.43	6.58	6.70	0.03	25.73	7.75	9.37	6.99	2.32	26.44	0.71
C3	16.07	14.64	4.09	0.41	35.20	4.88	29.14	1.41	0.39	35.82	0.62
D1	7.79	3.41	0.69	0.05	11.94	3.39	6.50	2.00	0.02	11.91	0.03
D2	14.20	17.12	7.12	0.06	38.50	5.90	24.99	7.00	0.02	37.91	0.59
D3	1.30	0.98	5.71	0.05	8.04	2.86	2.50	2.00	0.02	7.37	0.67
D4	7.88	7.81	16.61	0.05	32.36	5.00	19.48	7.92	0.15	32.55	0.19
D5	10.60	12.60	9.98	0.04	33.22	5.44	23.00	3.00	0.74	32.17	1.05
D6	12.18	7.24	29.30	0.05	48.77	1.61	26.39	20.81	0.24	49.06	0.29
D7	4.50	4.52	4.19	0.04	13.25	3.90	5.50	2.00	0.90	12.30	0.95
D9	15.82	12.01	2.78	3.73	34.34	7.46	15.99	10.01	1.87	35.33	0.99
D10	4.69	4.11	0.26	1.79	10.85	4.43	4.00	2.26	1.08	11.76	0.91
D11	19.71	14.06	0.39	3.63	37.80	3.61	27.00	6.99	2.10	39.69	1.89
D12	7.88	3.62	0.17	1.71	13.39	3.56	6.99	3.50	0.02	14.06	0.67
D13	2.80	2.14	4.44	0.04	9.42	3.54	2.87	2.00	0.41	8.82	0.6
D14	3.36	1.89	2.09	0.03	7.36	5.12	0.62	0.76	0.38	6.89	0.47
D15	4.99	8.06	6.96	0.04	20.04	9.60	5.00	3.52	1.76	19.88	0.16

Table 6. The water parameters for Irrigation.

	SAR	SSP (%)	RSBC (meq L^{-})	PI (%)	KR	MAR (%)
A2	1.02	28.21	-1.12	32.61	0.43	57.87
A3	0.18	3.51	-4.73	21.74	0.04	59.37
A4	0.51	13.06	-3.44	23.06	0.15	53.03
A6	0.32	7.14	-3.44	24.67	0.08	49.72
A7	0.39	8.87	-3.88	23.19	0.10	24.79
A8	1.35	31.85	-0.28	33.81	0.50	78.28
A9	2.82	31.89	-8.76	11.77	0.48	59.05
A10	0.67	15.83	-1.97	28.07	0.19	54.68
A11	0.57	8.27	-14.18	11.00	0.09	33.48
A12	2.40	34.43	-9.10	7.30	0.53	55.90
A13	0.12	1.33	-36.38	3.80	0.01	14.50
A14	0.17	2.04	-28.10	6.69	0.02	19.31
B1	2.28	21.57	-26.89	6.42	0.28	28.58
B3	2.26	22.34	-24.21	6.65	0.29	19.86
B5	1.24	12.00	-35.74	5.17	0.14	32.59
B6	0.14	2.55	-10.51	13.73	0.03	22.63
B7	0.55	8.48	-11.17	13.19	0.09	33.21
B8a	0.30	4.95	-10.26	14.49	0.05	24.64
B8b	0.28	4.21	-13.38	12.28	0.04	29.99
B9	0.13	1.94	-14.93	11.85	0.02	42.71
B10	0.84	11.63	-13.68	11.35	0.13	35.02
B11	0.43	6.53	-9.98	14.82	0.07	35.74
B12	1.12	17.15	-6.08	16.76	0.21	42.06
C1	3.11	34.54	-10.40	10.28	0.53	42.83
C2	2.17	26.03	-11.25	11.09	0.35	34.62
C3	1.04	11.61	-25.82	6.47	0.13	47.67
D1	0.29	5.78	-7.81	15.54	0.06	30.43
D2	1.80	18.49	-25.42	6.50	0.23	54.66
D3	5.35	71.02	0.58	21.88	2.50	42.99
D4	5.93	51.33	-10.70	7.44	1.06	49.77
D5	2.93	30.04	-17.76	7.33	0.43	54.31
D6	9.41	60.09	-17.81	3.20	1.51	37.28
D7	1.97	31.62	-5.12	15.27	0.46	50.11
D9	0.75	8.10	-20.37	9.01	0.10	43.15
D10	0.12	2.40	-4.38	23.24	0.03	46.71
D11	0.10	1.04	-30.17	5.57	0.01	41.64
D12	0.07	1.30	-7.95	16.17	0.02	31.46
D13	2.83	47.14	-1.40	20.53	0.90	43.32
D14	1.29	28.34	-0.13	31.12	0.40	36.02
D15	**2.72**	**34.71**	**-3.45**	**15.83**	**0.53**	**61.76**

CONCLUSION

The study area includes several types of rocks that store groundwater, dating back to the geological formations that spread in the region. They are represented by marl, limestone, and gypsum rocks belonging to the Fatha Formation, and sand rocks belonging to the Injana and Muqdadiya Formations. The quality of water is affected by the quality of reservoir rocks and exposed rocks, especially in topographically rugged areas such as the feet of the Ain Safra and Bashiqa mountains, as well as the soil covering the area containing clastic components of carbonate and gypsum, which represent the products of weathering and erosion of the rocks from which the soil is derived. Therefore, a large number of wells had a high TDS content as a result of high concentrations of sulfate and bicarbonate, in addition to calcium and magnesium. The chemical specifications were reflected the quality of water (WQI), from excellent to unsuitable water. The percentage of wells was 7% excellent water, 27% good water, 34% poor water, 12% very poor water, and 20% unsuitable water for domestic use. These categories were generally divided the studied area into six regions, interspersed with some locations that were affected by the type and intensity of activity there.

The ratio (SAR < 10) and the percentage of sodium (SSP%) does not exceed 75% indicates a low soda content, and thus the well water source is suitable for irrigating most crops and all types of soil, the amount of RSBC values < 1.25, the Kelly ratio (KR < 1) and permeability index (PI < 75%) have no effect on the soil properties and negative impact on the quality of irrigation water.

DATA AVAILABILITY STATEMENT

The author confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

USE OF AI FOR WRITING ASSISTANCE

Not declared.

ETHICS

There are no ethical issues with the publication of this manuscript.

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