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Sulphates Suggested Guide Groundwater Quality for Irrigation, in the Eastern Regions of Nineveh Governorate.

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ABSTRACT

The quality of the water used for irrigation depends on the total amount of dissolved salts, their species soil properties, and crop type. One hundred thirty-nine samples were taken from wells in the east regions of Nineveh Governorate to analyze their physical and chemical properties. Wells water was assessed for irrigation purposes based on the following guides; (SAR), (BSRC), (SSP%), (PI), and (KR). The results showed that the suitability of water for irrigation use that nearly (97%) of samples was excellent based on (SAR) and (BSRC) guides. While the suitability of wells water was (47%) based on (SSP%) guide. Also, the results show that (68%) of wells have good permeability for the PI index and (96%) are suitable by (KR) guide for irrigation. According to the hydrochemical investigation, modified quality facies (R3) have been suggested where (Ca-SO4) is the dominant species This guide was developed based on sulphate as one of the important irrigation criteria in the study area. The results of the application of this index show that (11%) are excellent, (26%) good, (45%) are suitable, (15%) doubtful, and (3%) are unsuitable.

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دليل الكبريتات المقترح لجودة مياه الري الجوفية في المناطق الشرقية لمحافظة نينوى

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الملخص

تعتمد نوعية المياه المستخدمة للري على كمية الأملاح الذائبة الكلية، وخصائص التربة المروية، ونوع المحصول المزروع. تم أخذ مائة وتسعة وثلاثين عينة من الآبار الواقعة في المناطق الشرقية من محافظة نينوى لتحليل خواصها الفيزيائية والكيميائية. تم تقييم مياه الآبار لأغراض الري بناءً على الأدلة التالية: (SAR)، (BSRC)، (SSP%)، (PI)، و (KR). أظهرت النتائج أن صلاحية المياه الابار للاستخدام لأغراض الري بنسبة (97%) هي ممتازة بناءً على دليلي (SAR) و (BSRC). في حين بلغت نسبة مياه الآبار الملائمة (47%) حسب دليل (SSP%). كما أظهرت النتائج أن (68%) من الآبار تتمتع بنفاذية جيدة حسب مؤشر PI و(96%) صالحة للري بدليل (KR). وفقا للبحث الهيدروكيميائي، فقد تم اقتراح السحنات ذات الجودة المعدلة (R3) حيث أن (Ca-SO4) كانت من النوع السائد. تم تطوير هذا الدليل على أساس الكبريتات باعتبارها واحدة من معايير الري الهامة في منطقة الدراسة. واظهرت النتائج بعد تطبيق هذا المؤشر أن (11%) ممتازة، (26%) جيدة، (45%) مناسبة، (15%) مشكوك فيها، و(3%) غير مناسبة.

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Introduction

Groundwater has been steadily exploited for agriculture in Iraq, which has led to a decrease in its level and a change in its quality. Groundwater may be present in an area in abundance, but its quality is not appropriate, so it must be characterized by an appropriate quantity and quality in order to be suitable for agricultural use. The quality of groundwater for irrigation includes physical and chemical properties. The main group was adopted, which included the potential of Hydrogen (pH), electrical conductivity (E.C), total dissolved salts (TDS), in addition to cations and anions. The wells were studied for irrigation by Shihab et al. (2009) of selected areas of Nineveh Governorate, and it was found that (37%) of the wells were unsuitable for agricultural use according to the percentage of sodium absorption, while (7%) of the wells had water suitable for agriculture provided that the soil was washed continuously, and (33%) of them were suitable for coarse soil, while the rest of the wells were suitable for most types of soil. Al-Salim (2009) studied the groundwater quality of selected areas northeast of Mosul city used for irrigation and drinking purposes, according to the risk of salinity, where most of the samples fall into the very high salinity and medium sodium area that cannot be used for irrigation. Al-Hayali (2010) studied the quality of well water in the city of Mosul and its suburbs and its suitability for drinking and irrigation, as the water was described as suitable for irrigation of some salt-tolerant crops.

This study aims to submit a proposal classification derived from the nature of the region's water based on sulphate Concentration, which constitutes the largest part of the total dissolved salts and dominated anion among the rest of anions, because conventional irrigation variables do not meet the purpose in this region in describing the nature or quality of irrigation water. In addition to, knowing the ranges of sulphates and the extent of their impact on soil and crops. The importance of studying the quality of irrigation water reflect the suitability for irrigation without cause a formation of saline or alkaline soils, in addition to giving evidence and an indicator of whether this type of water causes toxicity to plants and crops when long-term irrigation.

Location of the Studied Area

The studied area is in the east region of Nineveh Governorate, northern Iraq, between latitudes (36°00'00") and (36°45'00") North, and longitudes (42°45'00") and (43°45'00") East. It includes part of Mosul city (the centre of the governorate) and the areas of Hamdaniyah, Namroud, Bashiqa, Talkaif and Wana provinces. It is bordered by Jabal Qand to the north, Jabal Bashiqa to the northeast, Jabal Ain Al-Safra to the east, the Greater Zab River to the southeast and the Tigris River to south and west.

The studied area was divided into three regions; the first region is located southwest of Mount Qand toward Talkaif and Wana towns about (1244) km^2 (GDS, 2009), the second region extended southwest Mount Bashiqa topographically towards the Tigris River through Mosul city with an area of about (1273) km^2 (GDS, 2009), while the third region is located south of Ain Al-Safra Mountain, towards the Great Zab River and the Tigris River, that includes Al-Hamdaniya district about (1155) km^2 (GDS, 2009).

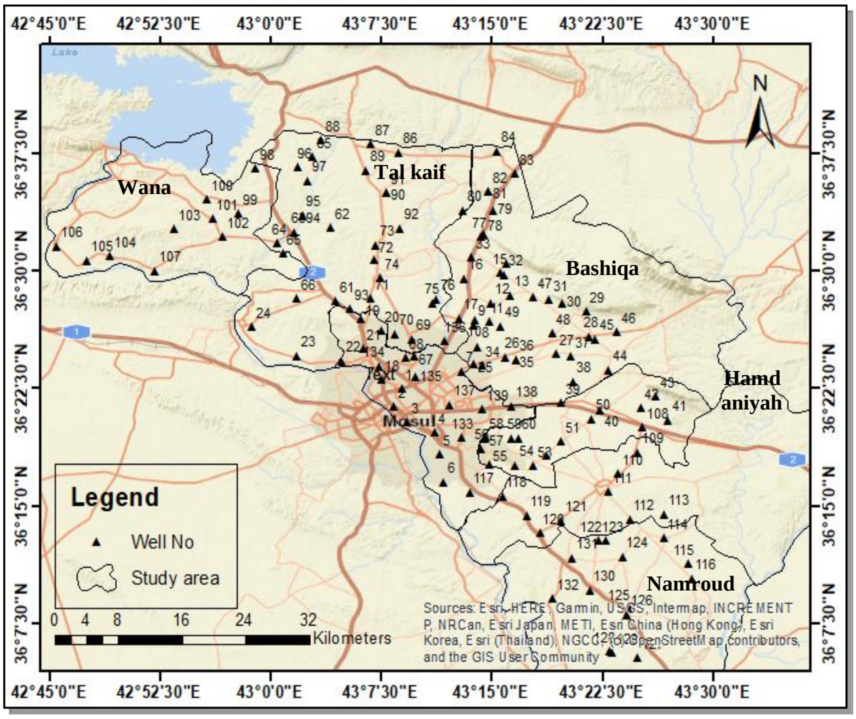


Fig. 1. The map of the studied area showing the locations of the wells.

Geology of the studied area

Qand fold is located north of the studied area and is a narrow and asymmetrical anticline that rises about (450) m.a.s.l., and the direction of its general axis is northwest-southeast. It consists of clastic sequences of sandstone, siltstone and claystone, and its rocks are characterized by their good ability to store water.

The Bashiqa and Al-Fadleya folds are represented as Jabal Bashiqa and are located in the north-eastern part of the studied area, they are two asymmetrical anticline whose axis is oriented towards northwest-southeast, and consist of the rocks of the Pila Spi Formation (Middle-Upper Eocene), which is represent the core of the two folds. Ain Al-Safra anticline represents the mountain of Ain Al-Safra. to the northeast of Bartallah town, its general axis direction is northeast-southwest, (Fig. 2). The Pila Spi Formation is the main component of the fold structure, characterized by fractures and systems of joints that allowed water seep inside the formation layers. Fat'ha Formation is found in the feet of Ain Al-Safra Mountain, and the Injana Formation is revealed in relatively distant flat areas (Zankana, 2005).

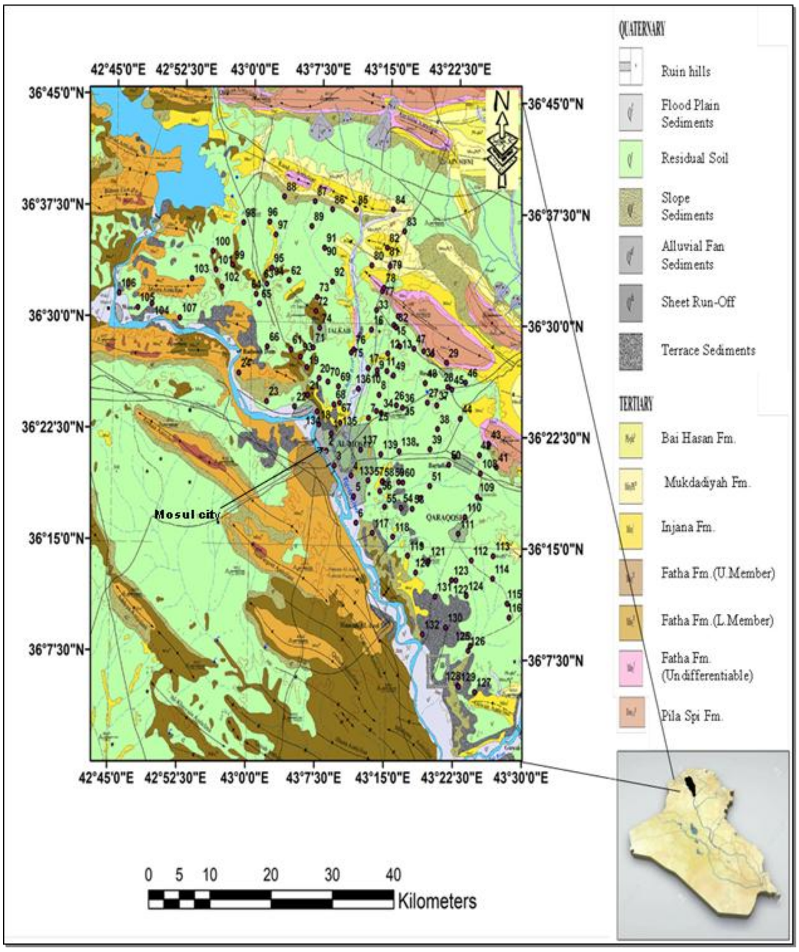


Fig. 2. A geological map Mosul city, Wana, Talkaif, Bashiqa, Hamdaniyah and Namroud This study aims showing the locations of the wells.

The Pila Spi Formation (Middle-Upper Eocene) is exposed in all anticlines in the north-eastern corner of Nineveh Governorate, and consists sequence of limestone, dolomite and dolomitic limestone (dolo-limestone), this formation stores a good amount of groundwater through caves, joints and fractures. While Fat'ha Formation (Middle Miocene) is outcrop at the feet of the aforementioned mountains and in many central and eastern parts of the studied area. The Fat'ha Formation represents the main aquifer in the central and southern parts around the city of Mosul, and consists sequence of gypsum, limestone, marl or claystone. The Injana Formation (Upper Miocene) is followed by Fat'ha Formation that consists of fine to coarse-grained sandstone and alternating claystone or mudstone, sandstone layers acting as a good groundwater reservoir.

Al-Mukdadiya Formation (Pliocene) is revealed along the limbs of several anticlines, and consists successively of gravel (pebbles) sandstone, pebbles claystone and calcareous sandstone (Al-Jiburi and Al-Basrawi, 2012). The lower parts consist of the Bai Hassan Formation (Upper Pliocene) consist of conglomerate, claystone and sandstone, while the middle part consists of coarse conglomerate and claystone, and the upper part consists of very thick layers of claystone alternating with thin and fine conglomerate (Al-Jiburi and Al-Basrawi, 2012).

Quaternary Deposits (Pleistocene) generally consist of weathering and erosion products of the above formations in the form of river terrace sediments, slope sediments, floodplain sediments and soil (Al-bana', 2002) Fig.2.

The climate of the region is subject to arid and semi-arid areas and is influenced by the Mediterranean climate, it is characterized by general characteristics based on the data of the virtual Mosul station taken from NASA, the MERRA-2 satellite, according to the following coordinates 36.40 N 43.11 E (Saeed and AL-Mohsin, 2022). The general temperature rate ranges from (9.66-33.21) C°, little rain at limited period of time. While the average annual rainfall for the past eight years in the hypothetical Mosul station is (312.96) mm, the annual general average relative humidity for 8 years was (42.84) % and the average annual wind speed for the past 8 years was (0.13-5.55) m/s. The study area is a rain-harvesting area and contributes to the nature of the earth's surface, soil and underground reservoirs, which is assisted by the large number of parallel valleys extending from the mountainous areas towards the plain areas. Rain is often the main source in recharging groundwater reservoirs, after heavy rains storm.

Materials and Methods

Sampling and analysis

One hundred thirty-nine water samples were collected from groundwater wells for the period from January to July 2021. The geographical coordinate of samples recorded using a mobile smartphone device. Each of (pH), electrical conductivity (E.C), temperature (T), and total dissolved solids (TDS) were measured at the site using a portable device. Chemical analysis was carried out according to standard methods (Federation, 2012) in the Laboratory of Geochemistry at Dams and Water Resources Research Centre, University of Mosul. The analysis included to measuring calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^{-}) and bicarbonate (HCO_3^{-}) by the titration method. Sodium (Na^{+}) and potassium (K^{+}) were measured by Flame Photometer type (GENWAY). Sulphate (SO_4^{2-}) and nitrate (NO_3^{-}) were measured by UV-Spectrophotometer type (OGAWA, OSK7724).

Statistical evaluation

The statistical treatments for the data set, and important parameters were calculated to determine.

Irrigation water quality guides

The current research included the assessment suitability of groundwater in the study area for irrigation and agricultural uses by calculating following guides.

The percentage of Sodium Adsorption Ratio (*SAR*) (equ.1), Residual Sodium Carbonate (*BRSC*) (equ.2), Sodium Percentage (*SSP%*) (equ.3), Permeability Index (*PI*) (equ.4), Kelley´s ratio (1963) (*KR*) (equ.5), Magnesium Adsorption Ratio (*MAR*) (equ.6), Chloride (*Cl*-), Salinity Potential (*PS*) (equ.7). Base Exchange Index (*R1*) and Meteoric Genesis Index (*R2*) are the main exchange index and the water origin index according to (equ. 8and9). (*R3*) modified from (*R1*) (equ.10) (Table 1). Wilcox and USSL diagrams were used to assess the irrigation quality of the collected water samples, and evaluate hydrochemical analysis by drawing modified Piper diagrams (Chadha, 1999), all ion concentrations were expressed in milliequivalents per liter (meq/l).

Table 1: The formula of irrigation water quality indices.

$SAR = Na^{+}/\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}$	Equ.1
BRSC=(CO32-+ HCO3-) - (Ca2+ + Mg2+)	Equ.2
SSP%=Na+/(Ca2+ + Mg2+ + Na+ + K+) *100	Equ.3
$PI = (Na^{+} + \frac{\sqrt{HCO3^{-}}}{Na^{+}+Ca^{2+}+Mg^{2+}})$ *100	Equ.4
KR= Na+/(Ca2+ + Mg2+)	Equ.5
MAR= Mg2+/(Ca2+ + Mg2+) *100	Equ.6
PS= Cl- + (0.5*SO42-)	Equ.7
R1=(Na+-Cl-)/SO42-	Equ.8
R2=((Na++K+)-Cl-)/SO42-	Equ.9
R3=(Ca2+-Cl-)/SO42-	Equ.10 (Modified from R1)

Results and discussion

Table (2) shows the ranges of physical and chemical properties of well water in the studied area.

Table 2: The statistical summary of the physical, chemical and irrigation parameters of the samples.

Parameter	Min.	Max.	Parameter	Min.	Max.
pH (unit)	6.80	8.50	*SAR*	0.06	15.48
E.C (µS/cm)	246.00	9321	*BRSC*	-80.02	4.23
TDS	*152.00	*6000	*SSP (%)*	1.08	77.26
T.H	*212.45	*4428.78	*PI*	**6.32	**92.99
Ca^{2+}	*22.44	*900	*KR*	**0.01	**3.48
Mg^{2+}	*10.75	*536	*MAR (%)*	2.16	75.20
Na^{+}	*4	*1500	*PS*	**0.70	**76.86
K+	*0.30	*83	*CAI-I*	**-5.40	**0.84
HCO_3^-	*58.56	*658.8	*CAI-II*	**-0.26	**0.67
SO_4^{2-}	*30	*5100	*CRI*	**0.00	**24.68
Cl^-	*1	*1932.29	*R2*	**-1.62	**2.82
NO_3^-	*0.50	*856	*R3*	**-0.86	**4.16

*in mg/l; ** in meq/l.

Physical properties of water

Potential of Hydrogen (pH): A variable that can be used to estimate the transport of chemical elements between water and soil and to measure the level of toxicity water and soil contamination (Król et al. 2020). The pH range in the wells of the study area was (6.8-8.5), where all wells fall within the permissible value of irrigation standards (Table 3). In general, soluble calcium, magnesium and potassium concentrations rise with low soil pH, but the effect of pH on calcium-magnesium solubility was more pronounced than potassium (Table 4), due to the soluble effect of calcium and magnesium in the medium with a lower pH rather than the cation exchange effect, which is the main mechanism for binding potassium to phases of soluble complexes that are not formed in the presence of calcium and magnesium (Almas et al. 2007). Using the classification of pH (Islam et al., 2016), it was found that (100%) of wells are suitable. (Table 5).

Electrical Conductivity (E.C), valued at the wells of the study area ranged from (246-9321) (µS/cm). (74%) of the wells fall within the permissible value of irrigation water standards and (26%) of the wells fall within the values not permitted value of irrigation water standards (Table 3). On the use of (Don, 1995) classification of E.C. in (Badmus et al. 2014), it was noted that (8%) of well are good, (40%) are suitable for plants and resistant to salinity, (26%) are suitable for plants with high salinity resistance, permeable soils and severe drainage system and (26%) are unsuitable for irrigation, (Table 5). The relationship of electrical conductivity with Sulphate is a strong direct relationship (R^2=0.79), which indicates that the largest part involved in the increase of E.C comes from high sulphates (Table 4).

Total Dissolved Solids (TDS) consist of inorganic salts (composed of mainly calcium, magnesium, potassium, sodium, bicarbonate, chlorides and sulphates) and little amounts of organic matter dissolved in water. The values ranged in the study area (152-6000) ppm, where it (87%) of the wells are suitable for irrigation, and (13%) are unsuitable, according to the irrigation water standards (Table 3). The (Don, 1995) classification of (TDS) was used in the study area to distribute wells according to categories. It was found that (1%) is excellent, (12%) is good, (54%) can be used, and (24%) is not guaranteed. And (9%) are not appropriate. (Table 5). There is a strong positive relationship between the total dissolved salts and sulphates (R^2 = 0.79), which indicates that sulphates represent the majority of the salt components. (Table 4).

Table 3: The assessment of wells water for irrigation standard parameters (Ayers and Westcot, 1985) of the studied area.

Water Parameter	Symbol	Usual range in irrigation water	Suitable Wells %	Unsuitable wells %
Physical properties				
Electrical Conductivity	EC	0-3 ds/m	74%	26%
Total Dissolved solids	TDS	0-2000 mg/l	87%	13%
pH	pH	6-8.5	100%	-----
Cation and Anion				
Calcium	Ca^{2+}	0-20 (meq/l)	78%	22%
Magnesium	Mg^{2+}	0-5 (meq/l)	81%	19%
Sodium	Na^{+}	0-40 (meq/l)	98%	2%
Potassium	K^{+}	0-2 (meq/l)	99%	1%
Bicarbonate	HCO_3^-	0-10 (meq/l)	97%	3%
Sulphate	SO_4^{2-}	0-20 (meq/l)	64%	36%
Chloride	Cl^-	0-30 (meq/l)	99%	1%
Nitrate-Nitrogen	NO_3^-	0-0.5 (meq/l)	5%	95%
Sodium Adsorption Ratio	*SAR*	0-15	98%	2%

Table 4: Correlation coefficient matrix for groundwater variables in the studied area.

Para-meter	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	SO_4^{2-}	Cl^-	NO_3^-	pH	E.C	TDS
Ca^{2+}	1.00**	0.30	0.38	0.02	-0.04	0.80**	0.36	0.17	-0.42	0.68*	0.68*
Mg^{2+}		1.00**	0.46*	0.01	-0.22	0.71*	0.3	0.10	-0.26	0.55*	0.56*
Na^{+}			1.00**	-0.02	0.17	0.63*	0.84**	0.16	-0.15	0.84**	0.85**
K^{+}				1.00**	0.16	0.03	-0.01	-0.02	-0.01	0.05	0.05
HCO_3^-					1.00**	0.02	0.04	0.16	-0.31	0.14	0.14
SO_4^{2-}						1.00**	0.41	0.02	-0.37	0.79**	0.79**
Cl^-							1.00**	0.25	-0.07	0.76*	0.77*
NO_3^-								1.00**	-0.21	0.25	0.26
pH									1.00**	-0.38	-0.38
E.C										1.00**	0.99**
TDS											1.00**

*p < 0.05, **p < 0.01

Chemical properties

Calcium is often one of the most concentrated ions in groundwater, due to the chemical weathering of carbonate and gypsum rocks represented by the minerals; calcite, Mg-calcite and dolomite of Pila Spi Formation, and gypsum and calcite of Fat'ha Formation. A strong positive relationship between calcium and sulphate (R^2=0.80) (Table 4) was also emerged, due to their presence in gypsum rocks and anhydrites in Fat'ha Formation. The concentration of calcium in the study area were (22.44-900) ppm. Most of the wells are suitable, (78%) and within the permissible range for irrigation, and (22%) are unsuitable according to the irrigation water standards. (Table 2), it is responsible for water hardness. Magnesium is one of the alkaline ions, it is the second most abundant cation in water. In the study area, the concentration was ranged (10.75-536) ppm, wells that are unsuitable for irrigation according to the permitted range were (81%), while (19%) within the permitted range according to the irrigation water standards (Table 3). Table (4) shows a strong positive correlation between magnesium and sulphate (R^2=0.71) due to the ion exchange between water and rocks (*as will be mentioned later*). Sodium concentration in the studied area ranges from (4-1500) ppm, according to the permissible limits for irrigation water standard, (98%) of the wells are suitable, it comes from the dissolving of halite. The concentration of potassium was ranged from (0.30-83) ppm, the wells indicate that they are suitable for irrigation by (99%) according to the irrigation water standards (Table 3). It is involved in the composition of clay minerals by adsorption and fixation on grain surfaces during the weathering process.

The main source of bicarbonate comes from weathering of calcite and magnesium-rich calcite and dolomite minerals in the limestone and dolomite that belong to the Bila Spi Formation, as well as limestone rocks in the Fatha Formation, and carbonate rock fragments found in the soil. Bicarbonates Ranged from (58.56-658.8) ppm. (97%) of the wells in the study area are valid in terms of bicarbonate, and (3%) are not valid in terms of irrigation water standards (Table 3).

Sulphates are one of the main ions found in groundwater of the studied area, it has a wide concentration of (30-5100) ppm. It plays an important role in biogeochemical cycles and is widely distributed in various environments. The high concentrations of sulphates come from natural sources due to the high solubility of gypsum ($CaSO_4.2H_2O$) and anhydrite ($CaSO_4$), and are released upon contact with water to these rocks in the Fat'ha Formation. (64%) of the wells are suitable for irrigation and (36%) are not suitable (Table 3).

Most of the chloride ions present in groundwater come from evaporite rocks that contain halite in the form of lenses within the gypsum rocks in the Fatha Formation, as well as secondary halite present within the upper regions of the soil. The chloride concentration was (0.01-1932.29) parts per million. Akhter et al. (2021) classification of chloride showed that (57%) of the wells had concentrations high enough to be unsuitable for irrigation and toxic to plants, (10%) of the wells fell within medium concentrations, and (33%) had low concentrations. The concentration of nitrates in the study area (0.50-856) ppm is (99%) of the wells are suitable, and (1%) of the wells are unsuitable according to the irrigation water standards (Table 3). Nitrates are found naturally in plants as a main nutrient. The source of nitrates in groundwater may be organic, atmospheric, or agricultural.

Irrigation water quality criterias

The irrigation water quality indexes are usually used to classify water based on physical and chemical properties to determine the fields of its usage, in addition to improve the natural qualities of the soil, which is reflected on productivity of crops.

The sodium adsorption ratio (*SAR*) is used to evaluate the relative concentrations of sodium, calcium and magnesium in irrigation water, and provides a useful indicator to know the potential adverse effects, especially of sodium on soil structure and permeability, (equ.1). Its values in the study area range from (0.06 - 15.48), when compared with the American Salinity Laboratory (Ayers and Westcot, 1985) of (Table 3), which fall within the permissible limits. Based on the classification (Turgeon, 2000) in (Awad et al. 2022), if the (*SAR*) is less than 10, no problems are expected on the soil and plant. Most of the wells (98%) of the study area fall within the water categories excellent and (2%) as a good for irrigation (Table 5).

Residual sodium carbonate (*BRSC*) is a popular way to assess the risks of sodium permeability and bicarbonate concentration and compare it to calcium-magnesium concentrations in irrigation water. Their values were found using (equ.2), and ranged in the study area of (-80.02−4.23) meq/l (Table 2). Turgeon (2000) stated in his classification that if (*BRSC*) has a negative value, it does not show problems on the soil and plants and this is shown by (97%) of the wells studied, while the positive value represents (3%).

Percentage of Sodium (*SSP%*), It is one of the indicators of damaging effects of sodium ion on the soil permeability and growing plants (Dhurandhar and Ranjan, 2020). It was calculated using (equ.3). The SSP% in the study area ranges from (1.08-77.26%) (Table 2). The classification of (Don, 1995) in (Awad et al. 2022) was relied upon to classify the study wells, if the SSP value is less than (20), it is from the category of excellent water for irrigation, where (47%) wells fell within this category, and (44%) wells whose values were less than (40) indicate a good water, while (5%) wells within the permissible category, and (4%) wells of doubtful suitability for irrigation (Table 5).

Soil permeability is affected by long-term use of irrigation water and is affected by soil contents of Ca^{2+}, Na^{+}, Mg^{2+} and HCO_3^{-}. Permeability Index (*PI*) was used in this study to assess the suitability of groundwater for irrigation using (equ.4). Its value in the study area ranged from (6.32-92.99) meq/l (Table 2). It was divided into three categories according to the classification developed by (Awad et al. 2022) from (Doneen, 1975). The first category is the excellent with a value greater than (75) that included only two wells in the study area, (68%) of the wells fell within the second category of good, whose values range from (25-75) and indicate that they are somewhat suitable for long-term agricultural irrigation with slight impact on the soil property, while the third category is the poor with a value less than (25) and appeared in (30%) of the wells as shown in (Table 5).

Magnesium Adsorption Ratio (*MAR*) represent the magnesium ion hazard concentrations. Values ranged from (2.16-75.20) meq/l (Table 2) according to equation (6). Using the classification (Paliwal, 1972) in (Awad et al. 2022), it was found that (62%) of the wells had suitable values compared to (38%) of the wells were unsuitable for irrigation with magnesium adsorption values greater than (50) (Table 5).

Kelley´s ratio (*KR*) is one of the parameters that are measured to infer the suitability of groundwater for irrigation, which was calculated using (equ.5). The values ranged from (0.01-3.48) meq/l (Table 2). A value less than (1) indicates good quality of irrigation water. A value greater than (1) is unsuitable for agricultural purposes due to alkaline hazards (Kant et al. 2015), while the (*KR*) when equal to the value (1) indicates that the concentration of sodium to calcium and magnesium is in an equilibrium. According to the classification of (Kelley, 1963) in (Awad et al. 2022), (96%) of wells are suitable and (4%) are unsuitable for irrigation (Table 5).

Potential Salinity (*PS*) It was calculated using by (equ.7). PS values ranged from (0.70-76.86) meq/l (Table 2). According to (Doneen, 1975) classification in (Awad et al. 2022), a value less than (3) indicates that the wells are suitable for irrigation and that their participation rate is very low, and represent (8%) from wells, while a value higher than (3) were prevalent in (92%) of the wells (Table 5). This indicates that the salinity potential in the groundwater of the studied area is almost high, which makes the water unsuitable for irrigation uses. Fig. (3) shows the strong relationship between sulphate and potential salinity with a correlation coefficient ($R^2 = 0.76$).

Base Exchange Index (*R1*) and Meteoric Genesis Index (*R2*) are used to distinguish the Groundwater Types and Hydro-Chemical Facies classified based on selected ions according to their concentrations in meq/l. that calculated by equations (11 and 12). R2 values ranged from (-1.62-2.82) meq/l respectively, according to the classification of (Soltan, 1998) in (Adimalla et al. 2018) (Table 2). When the sodium cation is replaced by calcium because it is dominant in the study area, in the original R1 (equ.11), the values reached (-0.86-4.16) meq/l (Table 2), the modified equation was given the symbol *R3* (equ.13), in case the value of *R3* is less than (1), the water quality of the wells is ($Ca\text{-}SO_4$) with a percentage of (94%), and if it is greater than (1), then the water quality of the wells is of the type ($Ca\text{-}HCO_3$) and it appeared at a rate of (6%). The wells of the study area were classified into (96%) of the wells of water-soil interaction origin because R2 is less than (1), and their water source is from the atmosphere by the condensation and filtration. while the rest of the wells (4%) were classified as water-rock interaction.

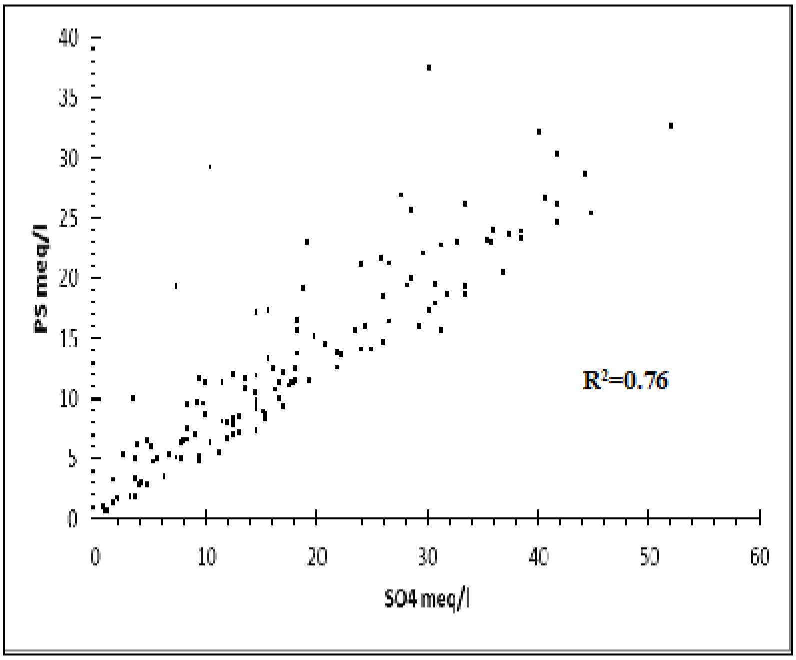


Fig. 3. The relationship between salinity (*PS*) and sulphates (SO_4^{2-}) in (meq/l).

Table 5: Groundwater assessment for irrigation of the studied wells.

Parameters	Range	Classification	No. of Sample	Distribution%
pH (Don, 1995)	6.5-8.5	No problem	139	100%
	5.1-6.4 and 8.5-9.5	Moderate	----	----
	0-5 and >9.5	Severe	----	----
Electrical Conductivity (E.C) (Don, 1995)	<250	Excellent	----	----
	250-750	Good	11	8%
	750-2000	Can be use	56	40%
	2000-3000	Doubtful	36	26%
	>30000	Unsuitable	36	26%
Total dissolved salts (TDS) (Don, 1995)	<175	Excellent	2	1%
	175-525	Good	16	12%
	525-1400	It can be used	75	54%
	1400-2100	Not guaranteed to use	34	24%
	>2100	Unsuitable	12	9%
Chloride (Cl-)	<140	High	79	57%
	140-350	Medium	14	10%
	>350	Low	46	33%
Sodium Adsorption Ratio (SAR)	<10	Excellent	136	98%
	10-18	Good	3	2%
	18-26	Doubtful	0	---
	>26	Unsuitable	0	---
Residual sodium carbonate (RSBC)	<0	None	136	97%
	0-1.25	Suitable	1	1%
	1.25–2.5	Marginally suitable	1	1%
	>2.5	Unsuitable	1	1%
Sodium percentage (SSP %)	<20	Excellent	66	47%
	20–40	Good	61	44%
	40–60	Permissible	7	5%
	60–80	Doubtful	5	4%
	>80	Unsuitable	-----	-----
Permeability index (PI)	Class I >75	Excellent	2	1%
	Class II 25–75	Good	95	68%
	Class III <25	Poor	42	30%
Kelley´s ratio (KR)	<1	Suitable for irrigation	134	96%
	>1	Unsuitable for irrigation	5	4%
Magnesium Adsorption Ratio (MAR)	<50	Suitable	86	62%
	>50	Unsuitable	53	38%
Potential Salinity (PS)	<3	Suitable	11	8%
	>3	Unsuitable	128	92%
Meteoric genesis index (R2)	>1	Shallow meteoric (water soil interaction)	134	96%
	<1	Deep meteoric (water rock interaction)	5	4%
R3	>1	$Ca\text{-}HCO_3$Type	8	6%
	<1	$Ca\text{-}SO_4$ Type	131	94%

WILCOXL and USSL Classification

According to the classification of (Wilcox, 1955), it was found that (13%) of the water of the study wells extends from excellent to good, (33%) is in the category of good to permissible, (27%) is from doubtful to unsuitable, (26%) is unsuitable and (1%) is doubtful (Fig.4A). Using the U.S Salinity Chart to classify the quality of irrigation water USSL (U.S.A Salinity Laboratory Diagram) in (Richards, 1954), depending on *SAR* and EC for groundwater samples in the study area, (Fig.4B). it shows that (8%) occurred under class (*C2*-*S1*) (medium salinity-low sodicity, (27%) wells occurred in class (*C3*-*S1*) (high salinity, indicating that most groundwater samples are Unsuitable for irrigation of soils with limited drainage except in the presence of an efficient drainage network and crops that tolerate high salinity. (49%) of wells occurred in (*C4*-*S2*) (with high salinity - low sodicity), (1%) wells in (*C3*-*S2*), (1%) wells in (*C4*-*S2*) and (13%) wells over *C4* (high salinity-high sodicity).

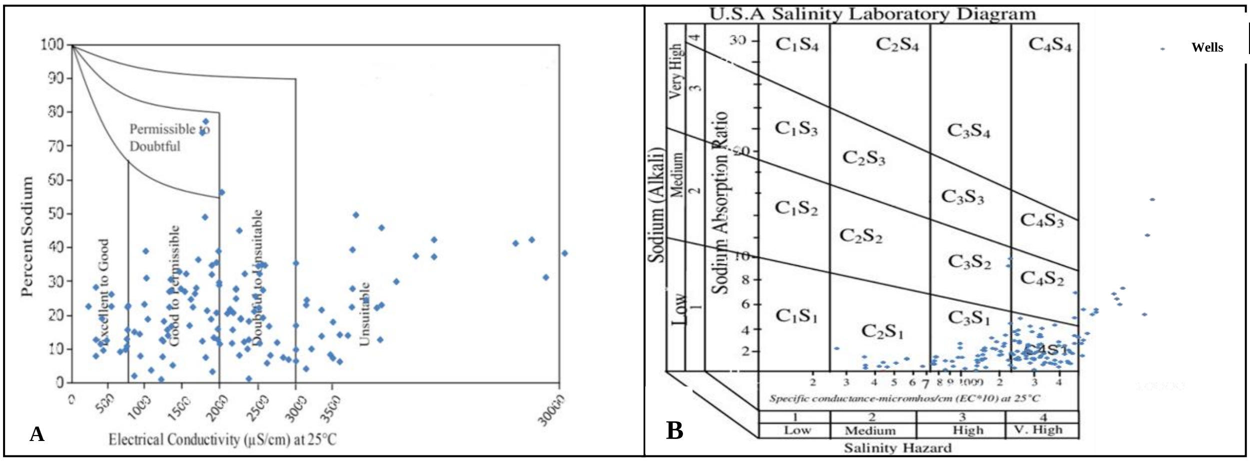
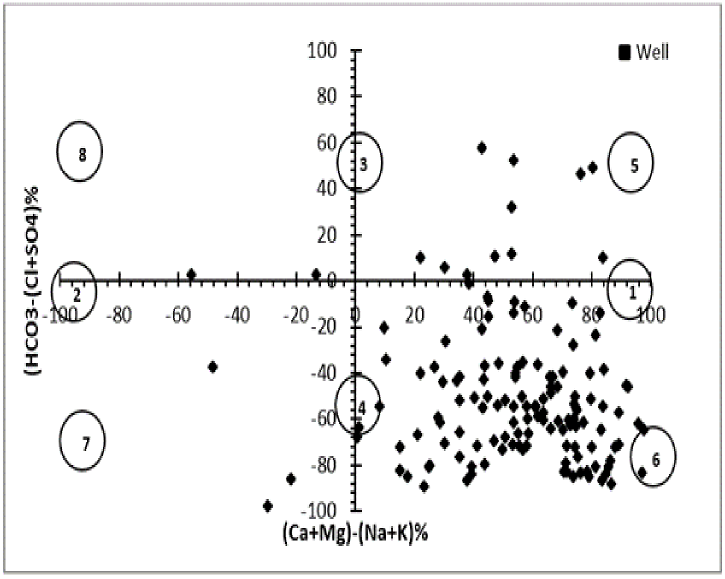


Fig. 4. A. Wilcox and B: USSL classifications of groundwater in the studied area.

The (Chadha, 1999) diagram in (Adimalla et al. 2018) which was developed from Piper (1944) diagram was used to get a preliminary conclusion regarding the origin of water in the fig.5, most of the water samples belong to the zone 6 type (Ca-Mg-SO_4) where (SO_4>HCO_3>Cl), this water characterized by permanent hardness and does not deposit residual sodium carbonate (*BRSC*) in soil by irrigation. As for cations, most of the water samples belong to Ca^{2+} and Mg^{2+} and to a lesser extent Na^{+} and K^{+}. This indicates that calcium is the dominant cation on the rest of the cations by its combination with the sulphates prevailing on the rest of the anions in the form Ca-SO_4 coming from gypsum. Well water in zone 5 is characterized by temporary hardness type of water (Ca-Mg-HCO_3) where (HCO_3>SO_4>Cl). Calcium is the dominant cation over the rest in terms of abundance in combination with bicarbonate to exist in the form of (Ca-HCO_3) coming from limestone. Zone 7 represents well water in which weak anions dominate relative to the rest anions.

Sulphate role in irrigation parameters:

Sulphate salts is less harmful when compared to chlorides, because only half of the sulphate ions contribute to salinity in the form of $CaSO_4$ while the other half remain in soluble form as Na_2SO_4 or $MgSO_4$ in the soil. This leads to the dominance of sodium in the soil solution and thus its effect on its chemical properties. Water with medium sulphates is used to irrigate crops that tolerate this type of water such as potatoes and rice, while those that tolerate high sulphate prefer to grow wheat, barley, flax and olives (Shamaa et al. 2015), cucumbers, tomatoes and onions, which cause an increase in vegetative growth qualities. Barley and livestock feed are preferably irrigated with high sulphate water. However, the continuous irrigation process with this water for many periods will lead to an increase in the salinity of the soil surface with time, and work on the difficulty of germination in the initial stage of the plant's life, which requires bringing water of low salinity to be used in the first irrigations to achieve the germination process. A number of irrigation water quality standards have been put forward by many researchers interested in irrigation management. Usually, the irrigation standards do not serve all agricultural usage as in the studied area, because the dominated high concentrations of sulphates, as well as the type of soil suitable for selected crops that tolerate high salinity and increase agricultural yield.



2. Alkali metals exceed alkaline earths.

3. Weak acidic anions exceed strong acidic anions.

4. Strong acidic anions exceed weak acidic anions.

5. Ca-Mg-HCO_3 type.

6. Ca-Mg-SO_4 type.

7. Na-K-SO_4 type.

8. Na-K-HCO_3 type.

Fig. 5. The (Chadha, 1999) diagram classification developed from the Piper chart showing the types of the studied wells.

High concentrations of SO42- ions lead to serious problems for the environment, especially in agriculture, such as acidification or damage to large parts of soil. The permissible limit for sulphate in irrigation water, which has been agreed upon by most researchers and according to the US Salinity Laboratory, is (20) meq/l (Table 3), including Jordanian Standard No. 893 of 2006 (Adimalla et al. 2018) and its benefits in increasing the production of most salt-resistant crops and fertility (Bauder et al. 2011). The oldest classification of sulphate was put by (Scofield, 1936) in (Hussain et al. 2010) that classified it into three categories: excellent, good and permissible. In this regard, (Eaton, 1950) in (El-Defan et al. 2016) developed the classification by adding a fourth field, which is Unsuitable. Both classifications are based on sulphate concentration in water. (Kovda, 1973) introduced sulphates among anions as a new determinant in irrigation water.

The increase in sulphates in the study area prompted the question of whether the current irrigation standards appropriately reflect natural conditions and serve the quality of crops suitable for cultivation under high concentrations in the study area. The natural conditions of the region require a sulphate irrigation classification added to water parameters to be applied to high-sulphate and low-sodicity areas.

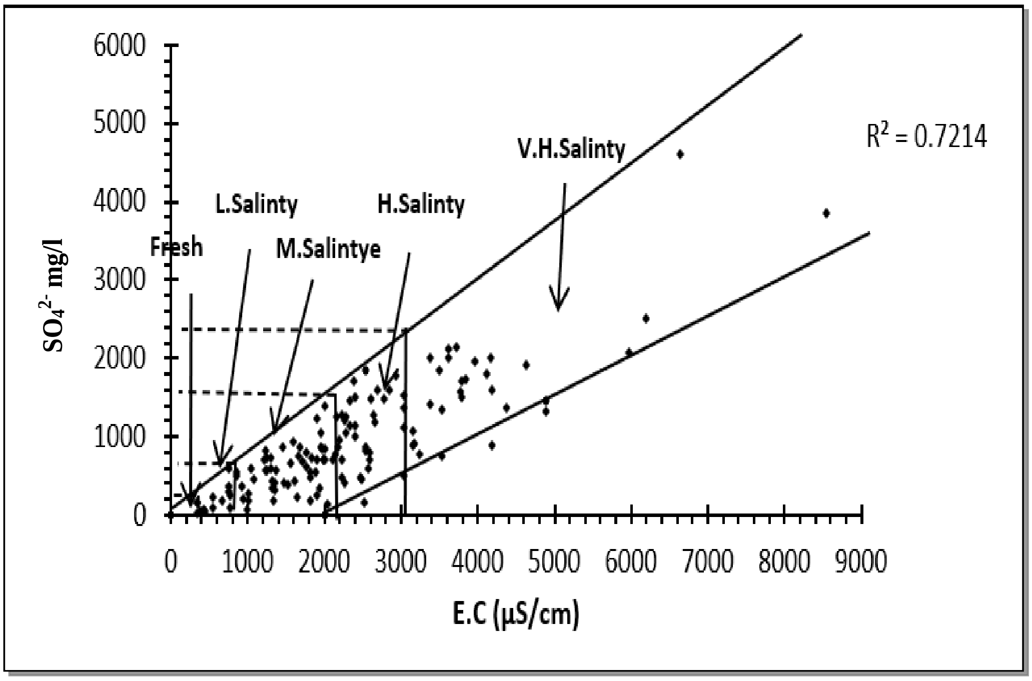
The proposed Classification of sulphate

There is a strong direct correlation between sulphate and electrical conductivity (R2=0.79), so the classification depending on E.C by (Don, 1995) in (Hussein, 2018) and sulphate were relied on to determine water quality. (Fig. 6A) shows the relationship between them and the proposed classification of sulphates, which consists of 5 classes, namely: <190 mg/l Fresh, <600 mg/l L.Salintiy, <1550 mg/l M.Salintiy, <2300 mg/l H.Salintiy and >2300 mg/l V.H.Salintiy.

Figure. 7B shows that there is no relationship between SO42- and SAR (R2 = 0.0002), which indicates that sodium parameters do not reflect the negative effect of high sulphate concentrations on water quality despite the appropriate SAR values. In the some wells whose water is suitable for irrigation according to SAR, the SO42- concentrations were high and therefore considered unsuitable for irrigation according to the proposed classification of sulphates. In this chart, a comparison was made between the limits of the (Eaton, 1950) classification and the proposed classification, where the difference between them appeared in the ranges of concentrations.

Table (6) shows the proposed classification and its comparison with previous classifications. There are similar distributions among the three classifications; E.C, TDS and the proposed classification of sulphate.

By applying the classification to the data of the studied area wells, it was found that (11%) of the wells fall within the fresh variety, (26%) of the wells fall within the low salinity variety, (45%) of the wells are medium saline, (15%) are high salinity and (3%) are very high salinity. compared to the classification of (Eaton, 1950) and (Scofield, 1936).



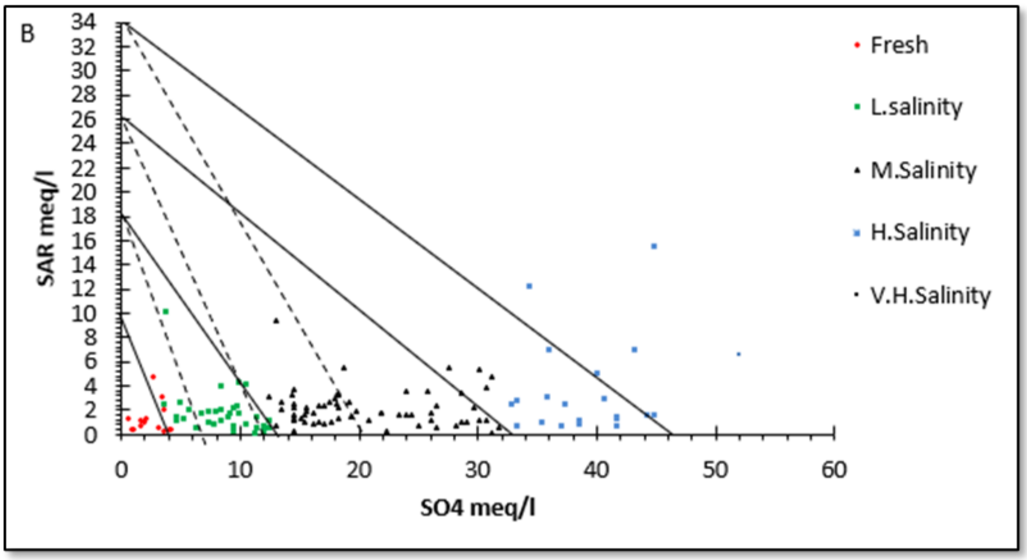


Fig. 6. Proposed classification of sulphate in the studied area, depends on: 6A: the relationship between SO_4^{2-} and E.C. 6B: the relationship between SO_4^{2-} and *SAR*. Dot line: The sulphate ranges in Eaton (1950). Solid line: The sulphate ranges in the present study.

Table 6: Permissible limits for classes of irrigation water (Scofield, 1936), (Eaton, 1950) and the proposed classification in the present study.

Class of water	Excellent	Good	Permissible	Doubtful	Unsuitable
E.C (µS/cm)	<250	251-750	751-2000	2001-3000	>3001
Samples and Distribution	(1) 1%	(11) 8%	(55) 40%	(36) 26%	(36) 26%
TDS *mg/l*	<175	176-525	526-1400	1401-2100	>2100
Samples and Distribution	(2) 1%	(16) 12%	(75) 54%	(34) 24%	(12) 9%
SO_4^{2-}(mg/l)					
Classification (Eaton, 1950)	<192	193-336	337-576	577-960	>961
Samples and Distribution	(15) 11%	(8) 6%	(24)17%	(40) 29%	(52) 37%
Classification (Scofield, 1936)	<192	193-336	337-960	>960.8	
Samples and Distribution	(15) 11%	(8) 6%	(64) 46%	(52) 37%	
Proposal Classification	Fresh	L.Salintiy	M.Salintiy	H.Salintiy	V.H.Salintiy
SO_4^{2-}(mg/l)	0-190	191-600	601-1550	1551-2300	>2300
Samples and Distribution	(15) 11%	(36) 26%	(63) 45%	(21) 15%	(4) 3%

Conclusion

1. Based on traditional irrigation indices that include sodium as a basic variable in evaluating its suitability for irrigation due to its effect on soil permeability such as *SAR*, *SSP* and *KR*, it was noted that all of them gave an indicator or evidence of the suitability of water for irrigation more than 95%, while the other indices in which including sodium or not such as *PI*, *MAR and PS* were gave a wide range of suitability for well water for use in irrigation (67%, 62% and 8%) respectively.
2. The most of the well samples were (Ca-Mg-SO_4) type where (SO_4> HCO_3>Cl), and a few wells were (Ca-Mg-HCO_3) type where (HCO_3>SO_4>Cl).
3. In general, there is no negative effect of sulphate on plants and soil if it is within the permissible range of irrigation water parameters, as it was noted that (64%) of well water is suitable for irrigation. While increasing its concentration leads to damage to leaves and fruits, especially in the early growth stages of plants.
4. Create the sulphate classification proposed consisting of (5) categories, which are < (190 mg/l) Fresh, < (600 mg/l) L.Salintiy, <(1550 mg/l) M.Salintiy, <(2300 mg/l) H.Salintiy, and >(2300 mg/l) V.H.Salintiy.

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