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Evaluation of Groundwater Quality Using the Water Quality Index (WQI) in Delta Wadi Sudr, South Sinai, Egypt

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Abstract:

Arid countries like Egypt need a lot of clean water for drinking, irrigation, and domestic usage. Given the increasing rate of population growth and urban development, it is crucial to assess groundwater quality to ensure suitability for various purposes. It is suitable for different purposes. . This study evaluates the groundwater quality in the Quaternary aquifer in Wadi Sudr using the WQI and several irrigation quality parameters. The study area's WQI and irrigation water parameters, such as RSC, SAR, KR, MH, Na%, and PI, were calculated to assess the suitability of groundwater for irrigation. Additionally, spatial variation maps of major ions and WQI for the Quaternary aquifer were created and interpreted. The results show that the groundwater is unsuitable for human consumption. Because TDS levels exceed 1000 mg/l, and the groundwater samples are classified as unfit water (WQI <100). However, the groundwater's trace element concentrations (Cu, Zn, Mn, and Ba) are within acceptable drinking limits. Kelly's ratios, PI, and MH, along with the areal distributions of EC, TDS, SO_4^{-2}, and Cl^- reveal that the groundwater of the Quaternary aquifer can be categorized as good to permissible for irrigation. However, the samples were plotted on the Wilcox and USSl Staffs. Salinity diagrams and show that the Quaternary aquifer samples are unsuitable for the same purpose.

Keywords: Wadi Sudr; WQI; Irrigation; Quaternary aquifer

1. Introduction

To resolve the food gap, the Egyptian government is interested in expanding its agricultural area, given the country's dense population. It has launched a number of initiatives, including the 1.5 million Fadden project, which is located in the southern valley, the Sinai, Upper Egypt, and the Delta. Due to the Ethiopian Renaissance Dam and climate, the state currently faces two issues: a shortage of surface water, symbolized by the Nile River, and a lack of rainfall water. So that it can carry out its strategy for agricultural expansion, the state has developed groundwater, which is the second source of water. Worldwide, almost two billion people depend on groundwater for agriculture and drinking [(1)]. In arid regions, groundwater usually serves as the main water source. Groundwater quality is greatly influenced by natural processes, including changes in climate, precipitation and mineral dissolution, exchange reactions, asymmetry in the seasonal distribution of rainfall, chemical weathering in different types of rock formations, interactions between so interaction between, rock, soil, and groundwater during flow and recharge, interaction between soil, rock, and groundwater during flow and recharge, interaction between soil, rock, and groundwater during flow and recharge, and rock and groundwater during flow and recharge, and seawater intrusion. On the other hand, anthropogenic activities include trash, over extraction of groundwater, industrial pollution, urbanization, and agricultural practices [(2 – 6)]**.** The studied area is the Delta of the Wadi Sudr Watershed. Ras Sudr is one of the cities of South Sinai Governorate and is located in an arid region, and the area receives just 4.1 mm of rainfall per year during the winter season. However, flash floods are the primary source of aquifer replenishment [(7)]. The Quaternary aquifer is primary source of groundwater in study area [(8)], the aquifer is made up of unconsolidated deposits consisting of gravel intercalated with colored clay and calcareous sandstone [(9 and 10)]. Groundwater recharge is dependent on the upstream watershed's frequent flash floods and on annual precipitation, which consists mostly of fractured basement and carbonate rocks [(7)]. Groundwater flows from east to west towards the Gulf of Suez, with depths ranging from a few meters near the coast to tens of meters inland. [(11)]. Groundwater withdrawal in these regions causes inland intrusion of seawater and salinization of groundwater at the interface, the over extraction of groundwater can lead to the depletion of the aquifer, up conning interface and the lowering of the water table [12, 13 and 8]. Groundwater pollution can be several factors contributing to this, including agricultural runoff, industrial waste, and sewage. Increased salinity in irrigation water causes the soil's TDS content to rise too much, which is detrimental to plant growth and yield. Though it has been displayed that when salts in the form of bicarbonates and carbonates are present, this restriction is only loosely enforced, and TDS should normally not exceed 1000 mg/l. An increase in sodium ions in irrigation water causes the soil to become harder and lose its permeability. Sodium ions exchange cations with Ca and Mg on clay to resulting in both effects. During this study, WQI are used to calculate the water's suitability for drinking by providing one value that represents the overall water quality at a given time and location. Groundwater quality for agricultural use has been evaluated by using irrigation quality parameters such as SAR, Na %, RSC, KR, MH, PI.

2. Study Area's Location

The Study Area is situated on the eastern side of the Gulf of Suez. (Fig.1) and it is covered about 90.0 Km^2. it is bounded by longitude 32.69 and 32.77 and latitude 29.61 and 29.72. The area under consideration lies on Sudr – El Tur asphaltic road. The area's primary drainage basin, Wadi Sudr (653.88 km^2) flows NE-SW and discharges into the Gulf of Suez. Ras Sudr is located downstream of Wadi Sudr in an arid coastal zone with low annual precipitation and high summer temperatures. Sudr basin rises from the east (El Tih Plateau and Egma highlands), with a maximum elevation of 760 m above sea level [14]. Groundwater is extensively used to meet water demand for irrigation and human use.

3. Geology and geomorphology setting of the study area

The Geomorphology of Wadi Sudr basin may be categorized into the following units: Structural plateau: it characterizes the western edge of El-Tih plateau (Fig. 2). Its surface is unfertile and was formed from Upper Cretaceous limestone. The elevated plateau is located between the scarp's foot zone and the sand dunes along the gulf shoreline. It consisted of unconsolidated deposits, lagoon deposits, and salt crusts. This portion of the plateau is divided by numerous valleys that extend to the west. Sand dunes run parallel to the Gulf shoreline and are made up of loose calcareous deposits. Hasanein (1989) concluded that the drainage pattern of Wadi Sudr is controlled by a NW-SE fracture system. This is completely consistent with the existing fracture system dominating the area. Many authors have studied the geology of Sinai and Wadi Sudr, including [15, 16, 9, 17 and 18]. The geology of Sinai can be classified as follows, based on previous study and the Geological Survey of Egypt's 1: 500,000 geologic map (Fig. 3) the area was divided into Wadi deposits (Quaternary age) found on Wadi floors. The majority of these deposits are composed of gravels and soft material. Sabkha deposits (Quaternary age) are composed of carbonates, evaporates, fluviatile, aeolian, and marine debris, which are occasionally cemented with carbonate or gypsum. The Pleistocene and Holocene sediments cover the area's main channels. Its cover both the main stream of Wadi Sudr and the coastal plain near the wadi's delta. These deposits can reach a thickness of 100 m and consist mostly of fractured basement and carbonate rocks [7]. Quaternary deposits cover the main stream of Wadi Sudr as well as the coastal plain at the wadi's delta. The delta deposits are divided into two units:

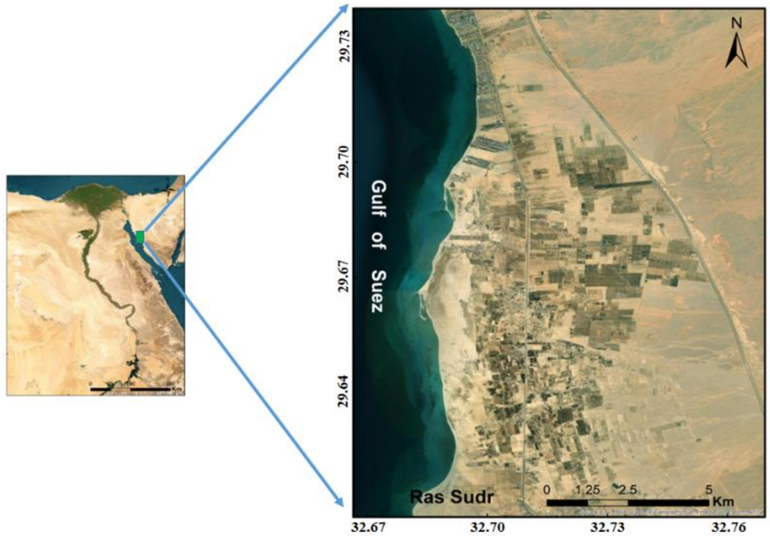

Figure (1): Location map of study area

The upper unit is the main unit, made of sand and gravel and measuring approximately 14 meters thick. The lower unit is made up of sand, sandstone, and clay, with interbedded gravel. The deepest well, drilled to 31 meters, did not reach the thickness of the lower unit [16]. A discontinuous thin shale layer of varying thickness separates the two units. Groundwater recharge is dependent on the upstream watershed's frequent flash floods and on annual precipitation and the Gulf of Suez serves as the Quaternary aquifer's natural discharge area. In the figure (4) shows the water level map in the study area, which the groundwater movement from southeast to northwest, and shows the depression found in the north of the area, which the water level range between (-2.5 to 5 m).

4. Material and Method

4.1. Sampling and analyzing groundwater

In January 2024, twenty-nine groundwater samples were collected from wells (Fig.5) that tapped into the Quaternary Aquifer.

The water samples were filtered to eliminate suspended debris that may dissolve when acid is applied. Clean plastic bottles (High-Density Polythene, HDPE) were used to collect two samples at each site. Two separate bottles were used: one for physicochemical analysis and another for metal analysis. Before collecting samples, the bottles are thoroughly cleaned with dilute HNO_3 acid and distilled water.

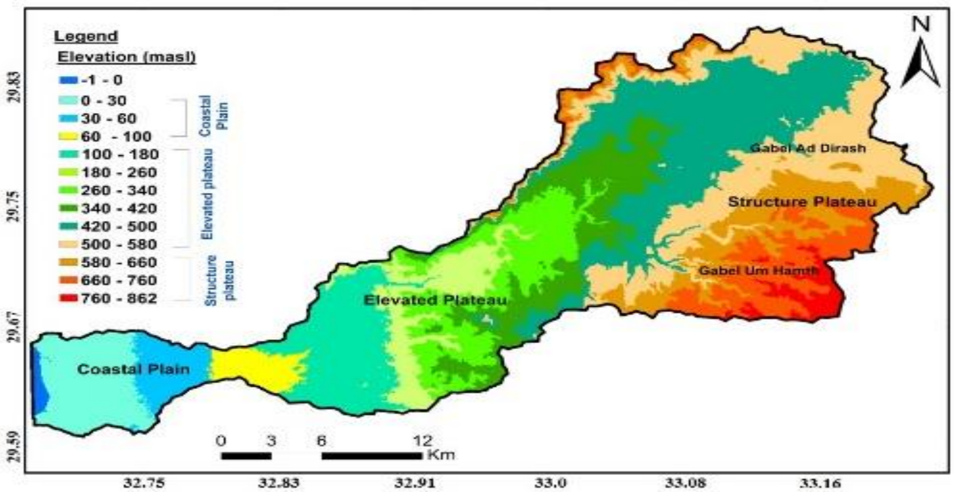

Figure (2): The Digital elevation map (DEM) reveals the geomorphological

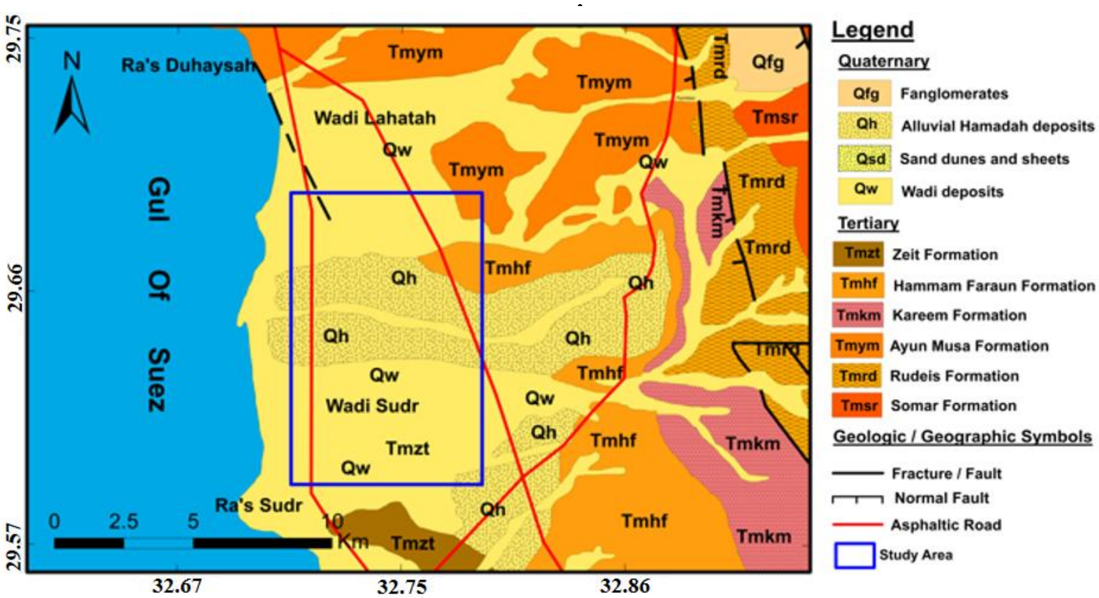

Figure (3): Geologic Map of the study after Egypt 1987 [(19)]

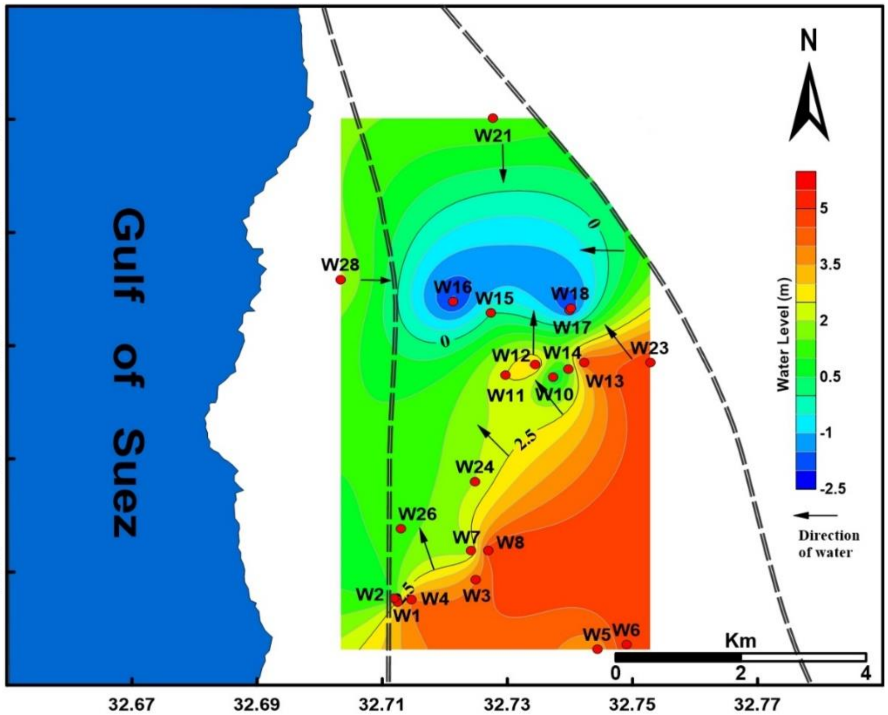

Figure (4): Water level map in the study

Samples were taken from open wells after 5 min of pumping and are filled. pH, EC, temperature and salinity were all measured in situ using multi- parameters. All samples were stored in an icebox and immediately transported to the lab. To determine the exact characteristics of the water quality. As per the guidelines suggested by [20] standard techniques. For analysis, nineteen samples were selected based on salinity and location. The hydrogeochemistry department laboratory of the Desert Research Centre analyzed groundwater samples using techniques that were adapted from [21], and the American Society for Testing Materials [22]. Using ion chromatography (Dionex, ICS 1100), analyses of chloride (Cl^-), (Ca^{2+}), (Mg^{2+}), (Na^+), (K^+), (SO_4^{2-}), and (NO_3^{2-}) were carried out. To fulfil the IC detection limit criteria, samples were diluted to a maximum electrical conductivity of no more than 800 µs/cm. By utilizing phenolphthalein and methyl orange indicators in a titration procedure against 0.01 N $_{H2SO4}$, CO_3 and HCO_3 were calculated. The findings of a chemical analysis are given in milligrams per liter, or mg/l. Every result from the water sample was within the allowable error range of ±5. Thermo Scientific's ICAP 6500 Duo is an inductively coupled argon plasma, was used to detect trace and heavy metals, such as Al, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn. Merck-Germany's 1000 mg/L multi-element

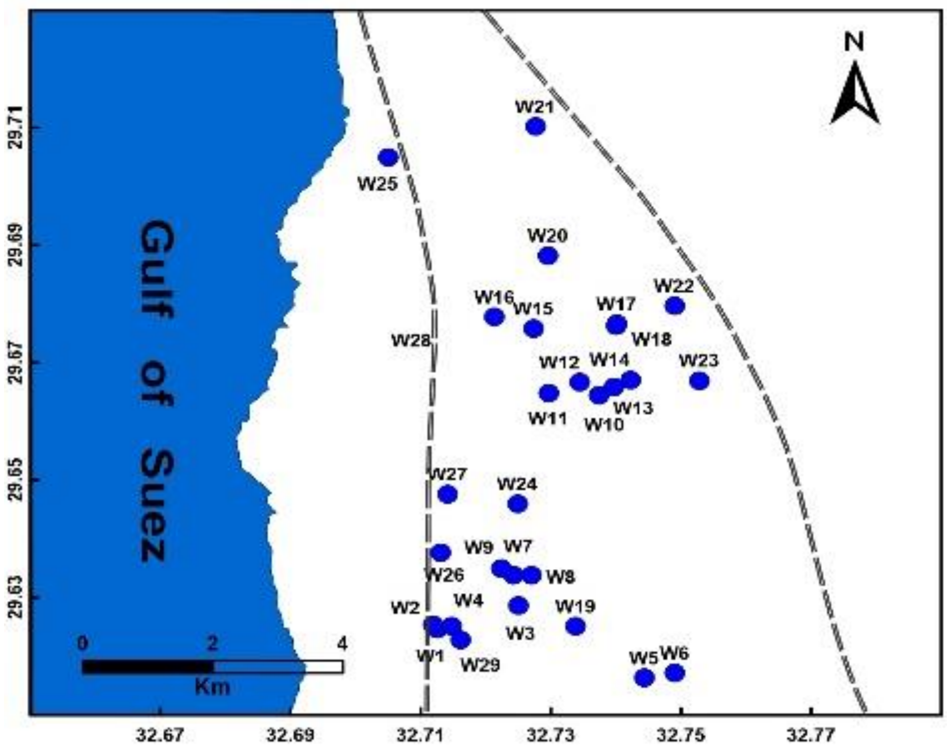

Figure (5): Well Location Map

certified standard solution was used as the stock solution for standardizing the instruments.

4.2. The Water Quality Index Method (WQI)

WQI is a rating that reflects the effect of multiple water quality parameters. Water quality indices are intended to provide a single number for the water quality of a source based on one or more systems. This converts the list of components and their concentrations in a sample into a single value. . Then, using each sample's index value, one could compare the quality of several samples [23]. Using the most commonly calculated water quality parameters, the weighted arithmetic water quality index approach classified water quality based on the level of purity [24]. In this study, the WQI was determined using the drinking water recommendations [25], which was computed using fourteen parameters with weights. These parameters are as follows: pH, TDS, Hardness, SO_4^{2-}, HCO_3^- ,Na+, Ca^{2+}, Mg^{2+}, K^+, Cl^-, , Al, Mn, Fe, and Zn. First suggested by Horton [26] and modified by Brown [27], the weighted arithmetic water quality index was created using the following formula:

$$\mathbf{WQI = \Sigma QnWn / \Sigma Wn}$$

Where,

- Qn is Quality rating for the nth Water quality parameter by using the following expression, according to [27]:

$$Qn = 100[(Vn - Vi / Vs - Vi)]$$

Vn= the actual value of the water quality indicator was determined by lab testing.

Vi = the Ideal value of nth parameter in pure water, (i.e.,0 for all other parameters except pH and dissolved Oxygen which are (7.0 and 14.6 mg/l respectively).

-Wi is the unit weight for each water quality parameter, which can be computed using the formula: $Wn = K / Vs$

Where,

K = constant of proportionality, which is calculated using the equation:

$$K = k = [1/\Sigma\ 1/Vs\ 1, 2, . . . n].$$

Vs = the standard allowable value for the nth water quality parameter.

The water quality index was categorized according to Brown et al., (1972) [27] and Chatterje and Raziuddin (2002) [28] in table (1)

Table (1): The water quality index based on WQI

WQI Value	Rating of Water Quality	Grading
0-25	Excellent water quality	A
26-50	Good water quality	B
51-75	Poor water quality	C
76-100	Very Poor water quality	D
Above 100	Unsuitable for drinking purpose	E

4.3. Water Quality for Irrigation.

Water quality for different uses (irrigation of crops, drinking by humans and livestock, etc.) is determined by the percentage and composition of soluble salts present. Consequently, water quality plays a crucial role in the sustainable use of water for irrigated agriculture, particularly in areas where salinity increases are predicted to be an issue [29]. EC, TDS, chloride, and sulfate are the main irrigation water parameters that influence whether the quaternary aquifer under study is suitable for irrigation [30]. The quality of irrigation water can be assessed using six fundamental parameters: (SAR), (RSC), (Na %), (KR), (MH), and (PI) as shown in table (2). Plotting the results of calculated parameters versus EC, such as Na% and SAR, is done with [31 and 32]. In general, the World Health Organization's approach focused on assessing groundwater's entire chemical profile to make sure it meets established health-based standards for drinking water quality. The entire balance and presence of several ions define the water's quality; no one significant ion is exclusively indicative of appropriateness. The following table 3 requirements for various elements, ions, and groundwater parameters according to world organization health [25].

Table (2): Irrigation water quality

Parameters	Equation (All ions in meq/L)	Reference
SAR	SAR = $\frac{Na}{\sqrt{Ca+Mg/2}}$	**(Richard 1954)**
Na%	Na% = $(Na^+ / (Ca^{2+} + Mg^{2+} + Na^+ + K^+)) * 100$	**(Wilcox 1955)**
RSC	RSC = $(CO_3 + HCO_3) - (Ca+^2 + Mg^{+2})$	**(Richard 1954)**
KR	KR = $Na^+ /Ca^{2+} + Mg^{2+}$	**(Kelley1941)**
MH	$MH = \frac{Mg}{Ca + Mg} * 100$	**(Paliwal 1972)**
PI	PI= $(Na^+ + \sqrt{HCO_3^-}) \times 100/ (Ca^{2+} + Mg^{2+} + Na^+ + K^+)$	**(Doneen1964)**

5. Results and Discussion

General chemistry of water:

Table (3) displays the results of statistical calculations for groundwater parameters.

We compared the data to World Health Organization-recommended criteria (2017).

5.1. Groundwater's physicochemical characteristics.

Results of physicochemical analyses of groundwater samples shows the groundwater's pH samples varied from acidic to lightly alkaline, ranging from 6.58 to 7.37, with an average of 6.99 (Table.3). (TDS) had an average of 7651 mg/L and varied from 2555 mg/L to 10006 mg/L. The east of investigation area had the lowest TDS value, whereas the west of study area had the highest TDS value. The groundwater samples are from brackish water (1000 < TDS >10000 mg/l). Groundwater samples electrical conductivity ranges from 4050 to 17500 µS/cm, with an average of 12821 µS/cm. The low value situated east of the research region and the high value situated west of the study location.

5.2. Major ions.

In groundwater samples, the main components of dissolved solids include cations such as Na, K, Ca, and Mg and anions such as Cl, SO4, and HCO3. Figures (7 a-g) display the distributions of the main ions in groundwater, while Table 3 lists their concentrations. The following can be determined by carefully examining these figures and Table 3:

1. Na ions range between 428 and 1620 mg/L, with an average of 1234 mg/L. The concentration of Na+ in groundwater increased toward the north, and exceeds the permitted level (> 200 mg/l).

2. The average potassium concentration is 11.8 mg/L, ranging from 5 to 33 mg/L. 63% of groundwater samples do not exceed the permissible limit (10–12 mg/L) and represented in the east of study area.

3. Ca ions range from with a range of 238 to 1204 mg/L, with an average calcium level is 856 mg/L, Figure (7c) illustrates the aerial distribution of Ca^{+2}. The calcium ion

concentration increases in the study area's west and northwest.

4. Magnesium (mg^{+2}) concentrations vary from 110 to 620 mg/L, with an average of 402 mg/L. Figure 7d depicts the aerial distribution of mg^{+2}, which shows that the magnesium ion concentrations increase toward the west and northwest of the study area. The concentrations in the study area are lower than the acceptable limits for human consumption (>50 mg/l).

5. The Chloride (Cl^{-}) content varies between 892 to 4228 mg/L with an average of 3175mg/l High chloride concentrations (>250mg/l) were found in the northern area of the quaternary aquifer, and the groundwater is unfit for drinking. The aerial distribution of Cl is illustrated in figure (7e). The chloride ion concentration increases toward the west and northwest of the study area. The study area indicate that their concentrations are below the (> 250 mg/L).

6. The spatial variation of $SO4^{-2}$ in groundwater (Fig.7f) reveals High concentrations that exceed the standard limits (>250 mg/l) in the western and northwestern portions of the aquifer, indicating that the groundwater is unfit for consumption.

7. Bicarbonate HCO_3^{-} levels were low in the aquifer. It fluctuated between 20 and 201 mg/l, with an average of 111 mg/l in the quaternary aquifer, and between 71 and 148 mg/l, with an average of 93 mg/l in the aquifer (Fig.7g).

5.3. Trace elements.

Groundwater contains trace elements, which are naturally occurring elements in extremely small amounts. Trace elements, which are present in small quantities, are vital to human health, whereas trace elements can be dangerous if their concentrations are higher than acceptable level [25]. Table 3 provides the concentrations of trace elements in groundwater, while Figures (8 a-f) show their distributions. Table 3 and these figures should be carefully analyzed in order to determine the following:

1. Copper, Zinc, Manganese, and Barium concentrations are below the permitted drinking levels.

2. The groundwater samples have iron contents ranging from 0.02 to 1.97 mg/L, with an average of 0.74 mg/L. The iron value is high in the east of the study area and low in the south of the study area. The concentration of iron in most wells is higher than the permitted level (> 0.3 mg/L).

3. The groundwater samples exhibit a content of nickel ranging from less than 0.002 to 1.13 mg/L, with an average of 0.37

mg/L. 31% of the samples have acceptable limits (0.07 mg/L), while other samples are above the limit set.

4. The average lead level in the groundwater samples is 0.54 mg/L, with a range of less than 0.009 to 2.21 mg/L. While some samples are beyond the limit, 47% of the samples are within acceptable limits (0.01 mg/L).

5. groundwater samples were found to have aluminum (Al) values ranging from < 0.01 to 3.84 mg/L, with an average of 2.07 mg/L. all samples exceed allowed limit (0.2 mg/L), except three wells.

6. All groundwater samples have boron concentrations below the recommended level (2.4 mg/L). With the exception of two wells, whose values are 3.13 and 5.309, exceed acceptable level.

5.4. The Water Quality index.

One of the most useful indices is the Water Quality Index (WQI) for evaluating and monitoring groundwater supply water quality. The WQI is an effective instrument for assessing groundwater quality and informing a variety of consumers about the water's condition. It makes it easier for regulators and decision-makers to access precise data and reports on water quality [33 and 34]. The WQI values for each water sample from the quaternary aquifer fall between 145 and 958. Due to the WQI exceeding 100, all samples were considered unfit for human consumption, according to results.

5.5. Classification of groundwater for irrigation needs according to Ayers 1977.

Ayers created a system of categorization for groundwater [35]. This categorization depends on the salinity and Na concentration of the water, two critical elements that might impact the water's appropriateness for agricultural irrigation. The set of water quality standards for irrigation water as shown in table (4).

5.5.1. pH

Groundwater samples' physicochemical analysis results (Table 3) shows that the pH of the groundwater samples varied from acidic to lightly alkaline, ranging from 6.58 to 7.37, with an average of 6.99. The center of study area had the lowest pH value, whereas the south of study area had the highest pH value. All samples fall within the permissible range. (pH 6.5–8.4) according to [30]. As a result, the groundwater samples may be used for irrigation without causing harm to the soil or plants. The pH of groundwater normally varies between 6.5 and 8.5, depending on the soil type and rock that interacts with it [36].

5.5.2. Electrical Conductivity (EC)

The concentration of total salt content in irrigation waters, as measured in EC, is the most essential indicator for determining irrigation water appropriateness. Except in some uncommon cases, such as particularly sensitive crops and severely clayey soils with little permeability, all irrigation waters with an EC of less than 2.25 μS/cm are deemed appropriate [36]. The electrical conductivity of groundwater samples ranges from 4050 to 17500 μS/cm (fig 6b). All water samples' EC exceeds the acceptable level, according to [30, 37 and 25]).

5.5.3. Salinity Hazard (TDS)

A salinity problem occurs when salt accumulate in the crop root zone to a point where it reduces production. In irrigated locations, these salts are frequently derived from a saline, high-water table or by salts in the applied water. [38]. Yield decreases occur when salts accumulate in the root zone to the point where the crop is unable to absorb enough water from the salty soil solution, resulting in water stress for an extended period. Plant symptoms resemble those of drought include wilting, a deeper, bluish-green colour, and thicker, waxier leaves. Symptoms vary with growth stage and are more noticeable if the salts harm the plant in its early stages of development. Mild salt impacts might sometimes go unnoticed due to a consistent loss in growth throughout a whole field.

Table (3): Statistical calculations of the groundwater parameters and WHO criteria.

Parameters	Max	Min	Average	Who Criteria 2017 (mg/L)
pH	7.37	6.58	6.99	6.5 – 8.5
Hardness	5463	1050	3802	100
EC μS/cm	17500	4050	12821	2000
TDS	10006	2555	7651	500 – 1000
Ca	1204	238	856	75
Mg	620	110	402	50
Na	1620	428	1234	200
K	32.8	4.6	11.82	10 – 12
HCO3	148	71	93	120 – 200
SO4	2772	805	1921	250
Cl	4228	892	3175	250
Trace elements				
Al	3.84	<0.01	2.07	0.2
Fe	1.97	0.02	0.74	0.3
Mn	0.31	<0.002	0.068	0.4
Zn	0.64	<0.007	0.13	3.0
Cu	0.77	<0.006	-	2.0
Ni	1.13	0.002	0.37	0.07
Ba	<0.01	<0.01	<0.01	0.7
Pb	2.21	<0.009	0.54	0.01
B	5.309	<0.004	1.51	2.40

The total dissolved solids (TDS) of ground water samples ranges from 2555 to 10006 mg/l. All water samples' TDS exceeds the acceptable level (< 2000 mg/l) [30].

5.5.4. Chloride Hazard

Small levels of Cl^- are important for plants, but excessive amounts can harm sensitive crops. Increased Cl^- in irrigation water hinder Plants absorb phosphates and phosphoric acid, which can be harmful to certain plants [39]. The chloride (Cl) concentrations in groundwater samples vary from 892 to 4229 mg/l [35 and 30], all water samples have Cl levels that are above the permissible range (< 350 mg/l).

5.5.5. Sulfate Hazard

Groundwater with sulfate levels between 805 and 2773 mg/l is not appropriate for irrigation, according to [30 and 37].

5.6. Classification of irrigation water quality according to parameters.

5.6.1. Sodium Adsorption Ratio (SAR)

SAR is computed to estimate the sodality or alkalinity danger of irrigation water, commonly known as Na^+ or alkali hazard. High salinity lowers plant osmotic activity and inhibits water from reaching branches and leaves, leading to a lower yield [40, 38 and 37]. The SAR is estimated using the following formula [41]:

$$SAR = \frac{\mathbf{Na}}{\sqrt{\mathbf{Ca+Mg}/2}}$$

Where the concentration is represented in meq/l.

The most commonly used value is the sodium adsorption ratio (SAR) proposed by Staff, 1954 [31]. The proposed diagram shows a plot of specific conductivity (in µS/cm at 25 °C) as a function of (TDS) concentration against SAR (Fig 9a). Water is classified by conductivity (C) into classes

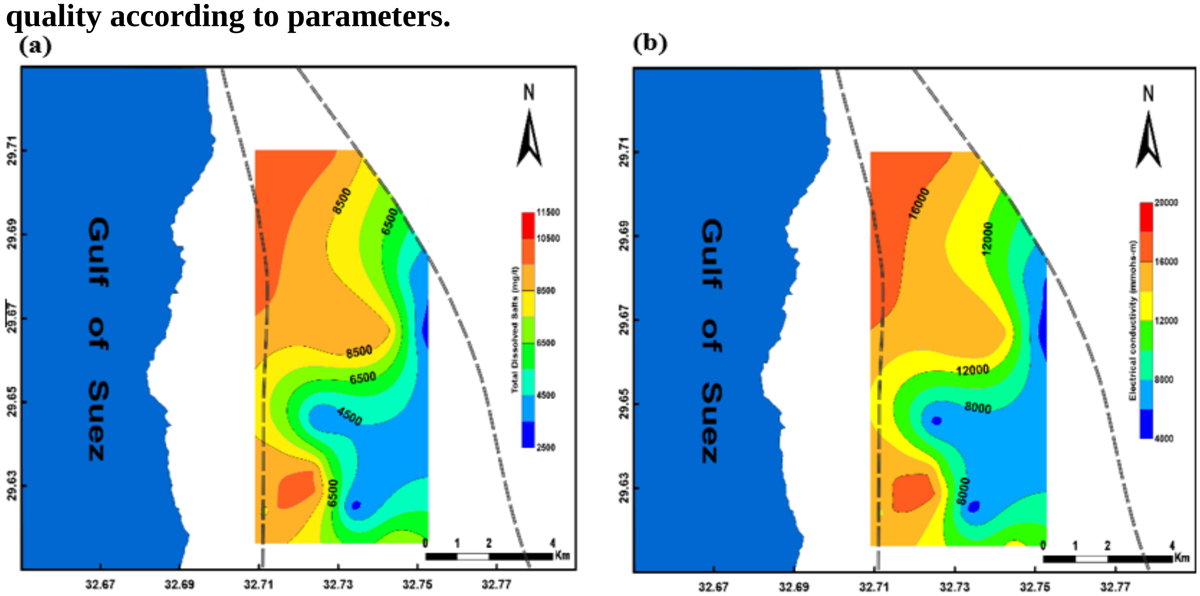

Figure (6): Spatial distribution of (a) Total Dissolved Salt and (b) Electrical Conductivity

C1, C2, C3, etc., and sodium adsorption ratio (SAR) into classes S1, S2, etc.

The comparison between the SAR of the samples and the US Salinity Laboratory Staff classification reveals that:

Three groundwater samples were plotted in C4-S2, two in C4-S3, and all of the others in C4-S4.

C4 is categorized by exceptionally high salinity (EC >2250 μ mhos/cm), requiring permeable soil and adequate drainage. It is also recommended to choose plants that tolerate salt. S2, S3, and S4 are characterized by water with medium, high, and extremely high salt concentrations, respectively.

5.6.2. Sodium Percentage (Na %)

Na^+ is a crucial ion in irrigation water classification because of its reaction with soil. High levels of sodium in irrigation water are considered undesirable as they can disperse soil aggregates and lower permeability. These effects occur when sodium ions exchange cations with Ca and Mg in clay minerals and colloids [42 and 43]. Soluble sodium percentage (SSP), which is another way to express the sodium in irrigation waters, is computed using a formula that was put out by [31] and uses meq/l to represent all ionic concentrations.

$$\mathbf{Na\ \% = Na / (Ca + Mg + Na + K) * 100.}$$

The calculated Na% and EC values are displayed in Wilcox's diagram (Fig. 9, b), which show all groundwater samples are plotted in unsuitable zone.

5.6.3. Residual Sodium Carbonate (RSC)

DE-flocculation of the soil due to the accumulation of sodium carbonates can occur when irrigation water includes CO_3^{--} and HCO_3^- at concentration higher than those of calcium and magnesium. This has a negative impact on agriculture and makes the agricultural area unusable [44 and 38]. The RSC is computed with following formula, all concentration by meq/l [44]:

$$\mathbf{RSC = (CO_3^{\ 2-} + HCO_3^{\ -}) - (Ca^{2+} + Mg^{2+}).}$$

Residual sodium carbonate of groundwater samples ranges from -19.0 to -108.0. This mean that the groundwater of aquifer displays values that are below the recommended limits and suitable for use in agriculture.

5.6.4. Kelly's Ratio (KR)

Kelley established Kelly's ratio (KR) as a measure of the harmful impact of Na on water quality for irrigation [44]. It refers to the sodium-to-calcium-to-magnesium ion ratio, which is calculated as:

$$\mathbf{KI = Na^+ / Ca^{2+} + Mg^{2+}}$$

Where the concentration is represented in meq/l.

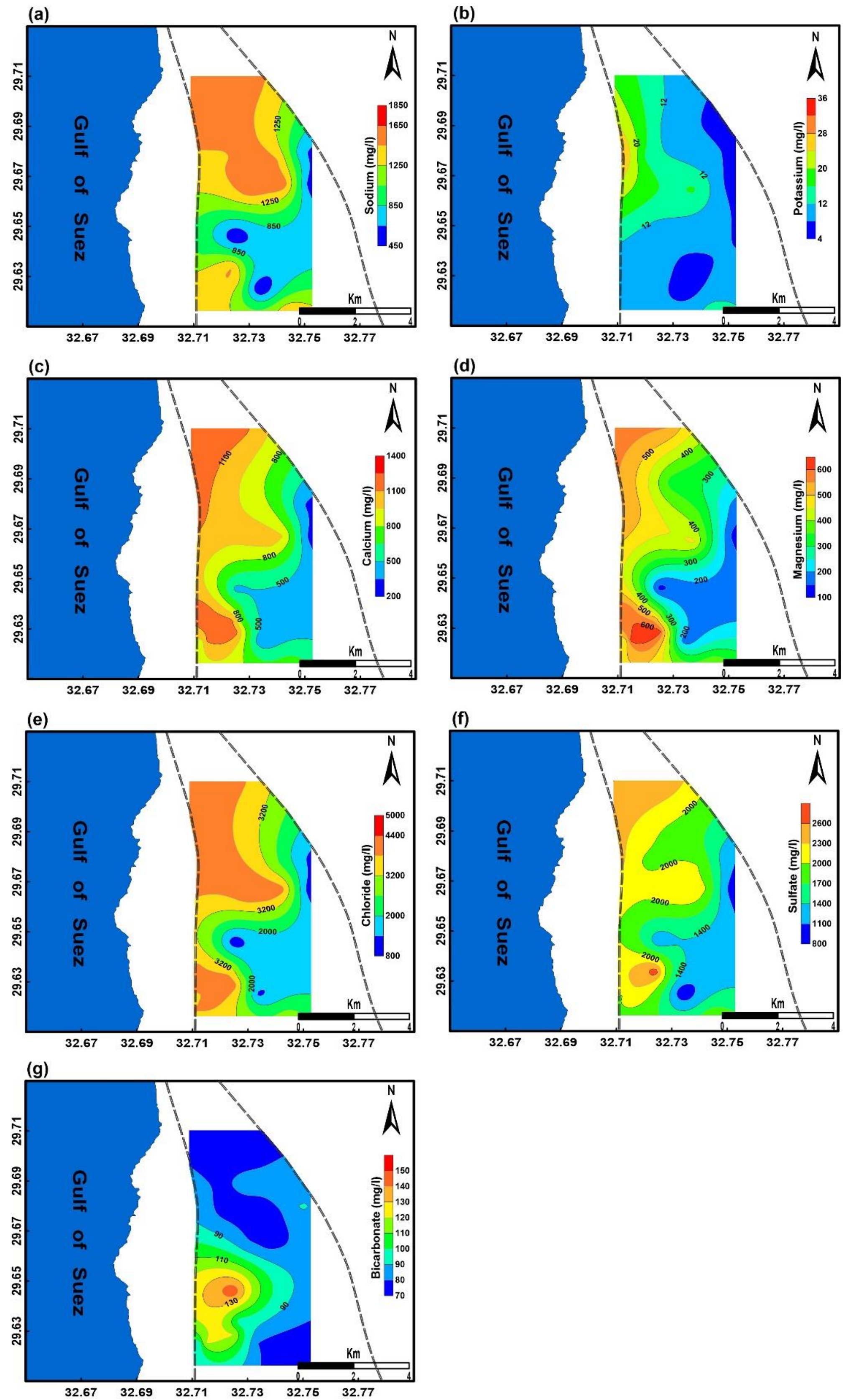

Figure (7): Spatial distribution of Cation and Anion in the study area. (a) Sodium, (b) Potassium, (c) Calcium, (d) Magnesium, (e) Chloride, (f) Sulfate and (g) Bicarbonate

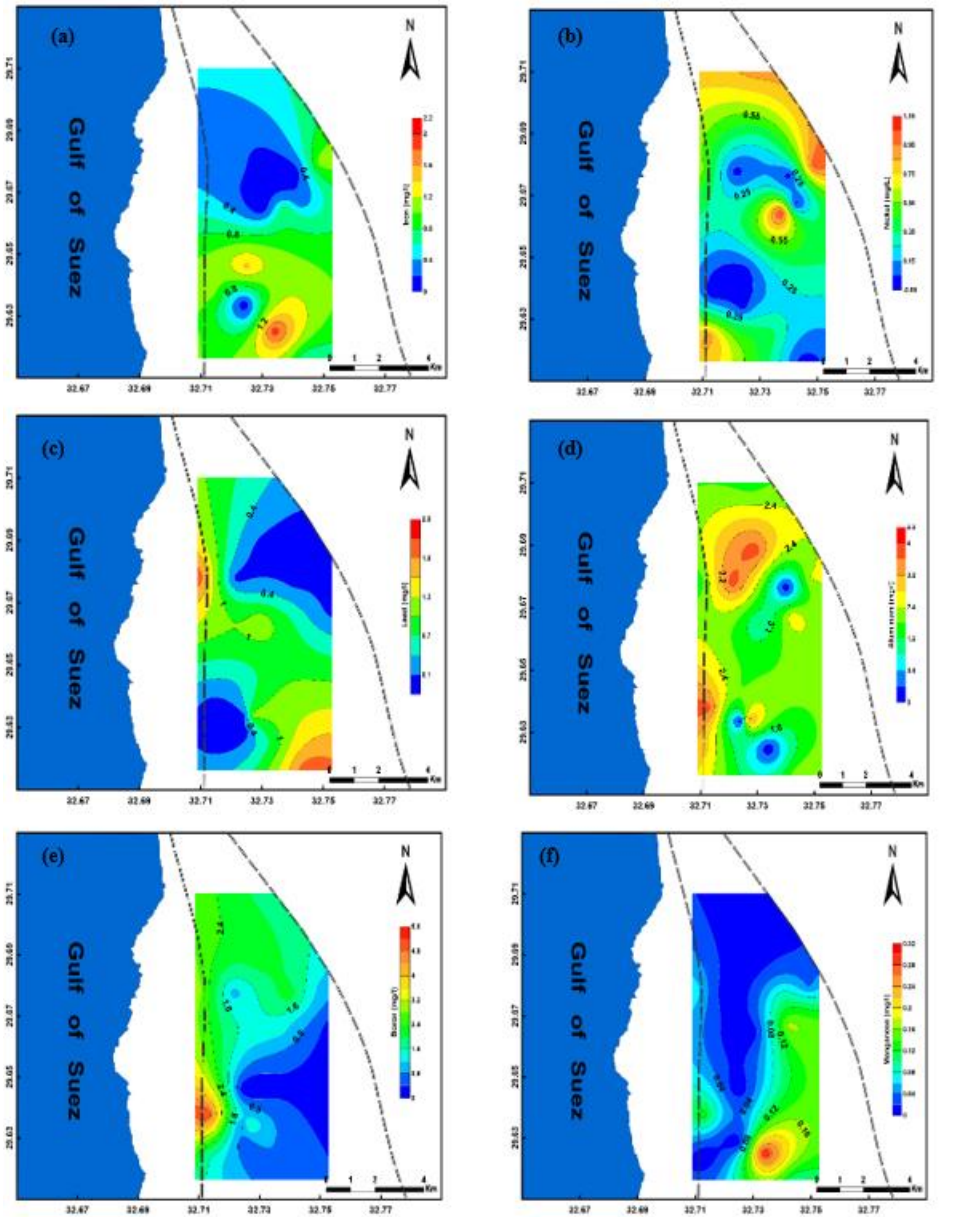

Figure (8): Spatial distribution of trace elements in the study area. (a) Iron , (b) Nickel , (c) Lead, (d) Aluminum , (e) **Boron and (f) Manganese**

Waters with a higher ratio are unsuitable for irrigation, those with a low KI (<1) are suitable. In the investigated study, Kelly's ratio of G.W samples ranges from 0.429 to 0.955 as shown in table (4), which indicates the groundwater is suitable for irrigation.

5.6.5. Magnesium Hazard (MH)

Calcium and magnesium are in equilibrium. In most waterways, but when dolomites predominate or, in certain cases, in soils with a marine origin, magnesium predominates [47].

Table (4): Parameters to evaluate and classify groundwater for irrigation according to Ayers 1977.

Constituents	Unit	Suitability for irrigation		
		Suitable	Marginal	Unsuitable
Ec	µS/cm	< 750	750-3000	> 3000
TDS	mg/I	< 500	500-2000	> 2000
Cl^-	mg/I	< 142	142-355	> 355
SAR		< 3	3-9	> 9
SO_4^{--}	mg/I	< 350	350-600	> 600

ID	TDS (mg/l)	pH	EC	Cl ppm	SO_4 ppm	SAR	Na %	RSC	KI	MH	PI
W1	8392	6.85	13800	3717.93	1988.31	9	41.77	-78.27	0.720	45.69	42.74
W3	9382	7.13	16200	4066.67	2058.81	8	35.75	-107.07	0.558	46.87	36.63
W4	9631	7.01	16250	4127.74	2247.47	9	36.84	-104.98	0.585	47.79	37.73
W5	7520	6.98	12800	2939.44	1929.08	11	47.44	-68.79	0.907	47.08	48.38
W7	9493	6.8	15700	3600.00	2772.98	9	39.77	-94.04	0.662	43.14	40.69
W8	7027	6.97	11500	2657.90	2088.74	9	43.85	-62.79	0.784	44.64	45.03
W10	9230	6.58	15800	4031.88	2199.33	10	42.44	-86.18	0.741	43.28	43.29
W11	9462	6.75	15400	4220.79	2171.78	11	44.64	-83.99	0.810	42.70	45.51
W13	8964	7.04	14550	4020.20	2007.60	11	47.68	-74.19	0.915	37.11	48.56
W16	8926	7.12	15050	4060.66	1910.00	9	41.07	-87.50	0.700	44.17	41.91
W18	7356	7.01	12500	2761.70	1975.58	11	48.76	-65.20	0.955	42.18	49.72
W19	3116	7.37	5200	1257.56	829.54	5	36.06	-31.48	0.566	40.50	38.36
W20	8172	7.02	13500	3529.23	1883.51	11	47.51	-69.99	0.908	37.33	48.45
W21	9804	6.91	16400	3906.75	2529.15	10	40.58	-101.67	0.685	44.30	41.27
W22	4110	7.2	6800	1528.54	1254.09	7	45.72	-34.11	0.847	49.10	47.70
W23	2555	7.31	4050	892.68	805.13	6	48.65	-19.55	0.953	43.41	51.72
W24	3362	6.75	5300	1030.81	1198.55	5	37.18	-31.14	0.596	31.32	40.25
W26	8867	7.21	15300	3761.34	2174.78	6	29.98	-106.28	0.429	45.24	30.95
W28	10006	6.82	17500	4228.98	2488.35	8	36.41	-106.30	0.577	44.23	37.30

A high concentration of Mg ions in water degrades soil quality and lowers agricultural yields. Greater Mg ion concentrations in water are usually the source of greater exchangeable Na ion levels in irrigated soils [48]. The following formula is used to calculate the magnesium hazard (MH):

$$\mathbf{MH = Mg / (Mg + Ca) *100}$$

Where the concentration is represented in meq/l.

The magnesium Hazard, often known as the index of magnesium danger, was first established by Paliwal [49]. Higher than 50% magnesium Hazard would have a negative impact on crop output as the soils become more alkaline. Magnesium Hazard of groundwater samples ranges from 31.0 to 49.10 % illustrated in table (4), which indicates the groundwater is suitable for irrigation.

5.6.6. Permeability index (PI)

Several soil cations, including bicarbonate anions and sodium, calcium, and magnesium, have an impact on the permeability of the soil. The following method is used to calculate the permeability index (PI), which [50] developed to evaluate the suitability of irrigation water:

$$\mathbf{PI = (Na + \sqrt{HCO_3}) / (Ca + Mg + Na) *100.}$$

Where the concentration is represented in meq/l.

A criteria based on permeability index (PI) for determining if water quality was suitable for irrigation and divided it into three classes [51 and 52]: Class I (> 75% appropriate), class II (25 – 75% acceptable), and class III (< 25% unsuitable). Permeability index of groundwater samples ranges from 30.0 to 52.0% as shown in table (4), which indicates the groundwater is suitable for irrigation.

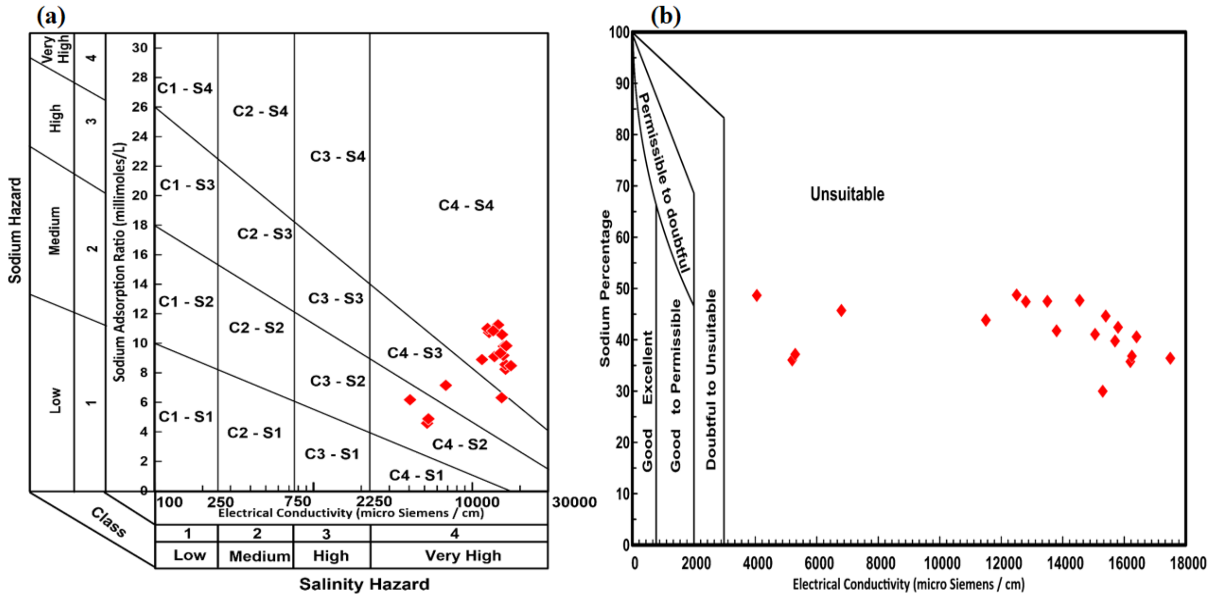

Figure (9): Classification of irrigation water quality according to (a) USSl Staff diagram, and (b) Wilcox's diagram

6. Conclusion

The groundwater quality of the quaternary aquifer for irrigation and drinking purposes in Ras Sudr district was evaluated in the current research using the WQI method and additional irrigation quality parameters. The results revealed that the aquifer's groundwater is not appropriate for human consumption due to the spatial distribution of main ions, TDS levels, and WQI. In the research area, the spatial distribution of main ions and TDS decreases from west to east. Certain trace element concentrations (Cu, Zn, Mn, and Ba) were within permissible drinking limits, whereas the concentrations of trace elements (Fe, Ni, Pb, B, and Al) in the quaternary aquifer's waters were unsuitable. The USSL diagram illustrates that the two groundwater samples are in the (C4–S3) class, the three groundwater samples are in the (C4–S2) class, and the remaining groundwater samples are in the (C4–S4) class. This indicates that the quaternary aquifer's groundwater is not suitable for irrigation. The groundwater samples fall into the unsuitable irrigation category, depending on the Wilcox diagram. The groundwater of the quarry aquifer is acceptable for agriculture based on irrigation water parameters: magnesium hazard (MH), sodium adsorption ratio (SAR), sodium percentage (Na %), residual sodium carbonate (RSC), Kelly's ratio (KR), and permeability index (PI). We highly recommended the evaluating the amount of water that can be produced by pumping test in order to prevent over-withdrawal, which raises salinity. Planting crops that can tolerate high salinities, such as acacia, palm, olive, and jujube. The east of the study region has low salinity, so it's suitable for cultivating a variety of crops.

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