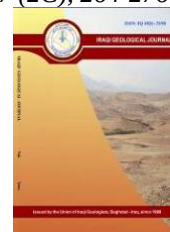




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Hydrochemical Characteristics and Spatial Variability in Coastal Aquifers Southern Iraq Utilizing a GIS Technique

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Abstract

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The present study investigates water quality regarding drinking and irrigation supplies by gathering and analyzing twelve groundwater samples south of Basrah, south Iraq. Many wells in the area concerned are exploited mainly for various industrial and agricultural activities, impacting the ground water quality. The standard guidelines recommended by the Iraqi Quality Standard limits and the World Health Organization have been used to determine the suitability of drinking. The physicochemical analyses showed that all sampled waters are unsuitable for the drinking supply due to high total dissolved solids (TDS) levels reaching 12925 mg/L. Four valuable indices have been applied for estimating the irrigated water quality, namely, the sodium adsorption ratio (SAR), the soluble sodium percentage (SSP%), the magnesium hazard (MH%), and Kelly's ratio (KR%). The results of water class as regards the percent of samples showed: SAR results, 25% excellent water, 41.7% good water, and 33.3% doubtful water; SSP% results, 16.7 % good water, 75% permissible water, and 8.3 % doubtful water; MH% results, 100% suitable irrigated water; and KR% results show 41.7% suitable water and 58.3 % unsuitable water. The USSS salinity diagram (Wilcox) result revealed 83.3 % of samples fall in very high salinity-very high sodium hazard class C_4S_4 , and 16.7 % of samples fall in very high salinity-high sodium hazard class C_4S_3 and very high salinity-medium sodium hazard class C_4S_2 , respectively. Increasing salinity of coastal aquifers has impacted sources such as seawater intrusion and intensive irrigation, and usages of excessive fertilizers and herbicides can largely pollute the groundwater quality.

Keywords: Physicochemical analysis; permissible limits; Spatial distribution; irrigated water indices; Dibdibba coastal aquifer; Iraq

1. Introduction

Groundwater, for many aquifers of the world, is considered a reliable resource for human requirements if it is protected from contamination. Those demands have quickly developed in recent decades due to population growth, increased irrigation, and the economy (Fatah et al., 2020). Intensive agricultural activity, overexploitation of wells, and uneven rainfall might lead to groundwater contamination (Chaudhary and Satheeshkumar, 2018). Due to rising evaporation and declining rainfall rates in arid and semi-arid areas, groundwater is increasingly exploited for industrial and irrigation usage (Alqurnawy et al., 2022). Expanding agricultural and anthropogenic activities on the environment might affect constituents chemistry and cause water quality deterioration (Kaur et al., 2017). Any change in the groundwater system is caused by geochemical factors such as rock-water interaction,

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soil-water interaction, and anthropogenic sources (Chaudhary and Satheeshkumar, 2018). The hydrochemical analyses have essential importance to detect the source of dissolved solutes in groundwater (Yan et al., 2020). Many geochemical processes are naturally affected by the chemistry of groundwater, which mostly involves dissolution and ion exchange (Ravikumar et al., 2013). The quantity of groundwater is significant to investigate, as well as its quality, which is responsible for determining the suitability of water for human, agricultural, domestic, and industrial purposes (Kaur et al., 2017).

In the south of Basrah, expressly the left side area of Khor Al-Zubair marine channel, where many wells are largely exploited, and various activities are ongoing so far, large harbors, more farms and plantations, petrochemical and fertilizers industrials, ice factories, water desalination plants, and more have contributed to consumption of groundwater. However, groundwater is an important source because it is inevitably irreplaceable for various usages. Many papers on hydrochemical situation in the area studied have reported:

According to the hydrogeological investigation discussed by Jassim and Joff (2006), the physicochemical analyses of 86 wells of groundwater revealed that the water of Dibdibba aquifer is brackish to saline class, and it is not recommended for human consumption or irrigation purposes due to high salinity, and overproduction from aquifer may cause inland movement of seawater through sediments of the Arabian Gulf. Abdulameer and Almallah (2018) calculated the groundwater quality. They concluded that agricultural and domestic sources are major reasons for increasing the content of elements, and the water is not appropriate for drinking and irrigation because of increasing levels of TDS. Almallah et al. (2022) studied groundwater quality using hydrogeochemical and isotope techniques. The stable isotope examined increasing groundwater deterioration; it enriched $\delta^{18}\text{O}$ values with increasing salinity, declaring mixing between upper unconfined and lower confined aquifer. Hamdan (2017) studied groundwater quality using physicochemical properties and the water quality index, and he concluded that wells were affected by seawater intrusion and water is poor to very poor class, unsuitable for human consumption and domestic supplies, and must be protected from contamination.

The Iraqi Quality Standard limits (IQS) and World Health Organization (WHO) suggest the standard guidelines for safe drinking water to understand groundwater's suitability for drinking and irrigation purposes. Exceeding ions on those limits may cause a health hazard when intensely intake. For that reason, the current study has several objectives including investigating the quality of groundwater by studying its properties, mapping the spatial distribution by detecting the zones of high and low values of the water's physical characteristics and chemical concentrations using a geographical information system (ArcMap GIS software), determining the suitability of the water for drinking by comparing its physicochemical values with safe drinking standard guidelines to identify sampled waters that exceed or within permissible limits, Assessing the suitability of the water for irrigation by calculating irrigation indicators, determining the wells that have high and low water salinity through Wilcox diagram applying AquaChem software, clarification the risks of increased irrigation by excessive pumping leads to seawater intrusion, in addition to the risks posed by heavy usage of fertilizers and agricultural pesticides.

2- Study area

Geographically, the area studied is situated in the south part of Basrah, south of Iraq, approximately 55 Km from the Arabian Gulf. It is positioned at latitudes $30^{\circ}6'0''$ - $30^{\circ}18'0''$ North and longitudes $47^{\circ}39'0''$ - $47^{\circ}57'0''$ East (Fig.1). The occupied area is approximately 421.75 Km² with an elevation of earth surface is approximately 62 m above mean sea level. Groundwater is inevitably an irreplaceable source of irrigation and industrial usage in the area. The drilling depth of wells is 10-25 m (Al-Qurnawy

et al 2023). Geologically, it comprised the Dibdibba formation and the Quaternary deposits. The oldest Dibdibba formation was deposited in the Pliocene (Tertiary) to Pleistocene (Quaternary) in the Alluvial deltaic environment (Jassim and Joff, 2006). Geomorphologically, the area studied is located within the Mesopotamian plain covered by sediments composed of gravel, sand, silt, and clay (Al-Naqib, 1967). The area studied is a flat plain with rising places and shallow valleys. The land mainly slopes down from the southwestern to the northeastern sides (Buday, 1980). Hydrogeologically, the area studied consists of two aquifer systems belonging to the upper Dibdibba Formation; the first shallow unconfined involves deposition layers of sand and gravel. The second is deeply confined to a semi-confined system. The two aquifers contain two different hydrochemistry of water, brackish and saline type, respectively. The two-meter thickness clayey stiff bed is a barrier between them; its hydraulic conductivity reaches 0.38 m/day (Alkubaisi, 1996).

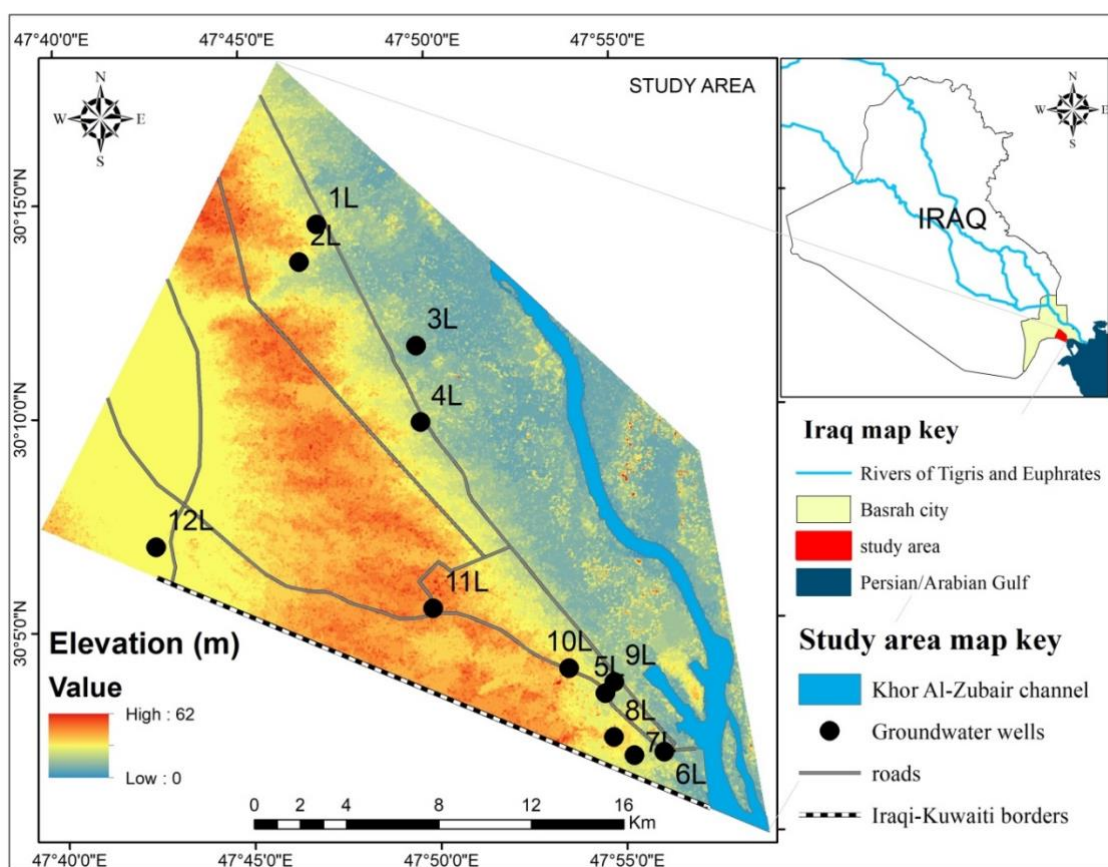


Fig.1. The studied area and elevation of earth surface above mean sea level

3. Material and Methods

3.1. Sampling and Chemical Analysis

Twelve sites were selected for the groundwater well modeling in June 2021 for hydrogeochemical work completion. The Ec was measured in situ by the electric conductivity tool. Two laboratories were selected to analyze the cations and anions of sampled groundwater. The first one, The Geochemical laboratory affiliated with the Marine Science Center/ University of Basrah for analyzing Na^+ , K^+ , Cl^- , HCO_3^- , and the other, The quality control laboratory affiliated to Basrah Water Directorate for Ca^{2+} , Mg^{2+} , SO_4^{2-} , and NO_3^- . The Flame photometric and Turbidimetric methods were used to analyze Na^+ , K^+ contents. The titration by Mohr method and titration with HCl were applied to extract the Cl^- and HCO_3^- concentrations, respectively, while the titration with EDTA (0.02N) was used to calculate the Ca^{2+} for

the test of Mg^{2+} . From observation of high concentrations related to Ec, TDS, TH, Ca^{2+} , Mg^{2+} , Na^+ , Cl^- , and SO_4^{2-} .

ArcMapGIS software (version 10.3) was applied to accomplish the hydrogeological work. It includes utilizing digital elevation model files (DEM) for 30 m resolution to extract the elevation of the earth's surface above sea level. The technique of interpolating a raster surface (raster map) from points is called 'Inverse Distance Weighting' IDW spatial analyst. It is important to construct spatial distribution maps of physicochemical elements and irrigation indices of sampled water. AquaChem software V.10.0 (2021) was also used to plot the Wilcox Salinity Diagram of groundwater samples.

3. 2. Irrigation Water Quality

3.2.1. Sodium Adsorption Ratio (SAR)

The sodium adsorption ratio represents an important parameter of water suitability for irrigation; the SAR shows the effectiveness of sodium ions in a soil-water exchange reaction (Gameh et al., 2020). Sodium alkali hazard means sodium replacing Ca^{+2} and Mg^{+2} in soils through an exchange that damages soil structure. SAR estimated by (Equation 1) based on Richards (1954) (Regional Salinity Laboratory US, 1954).

$$SAR = \frac{rNa^+}{\sqrt{r(Ca^{2+} + Mg^{2+})/2}}, \text{ (meq/L)} \quad (1)$$

3.2.2. Soluble Sodium Percentage (SSP%)

Increasing the concentration of sodium in irrigated water alters and destroys soil properties. Soil has calcium and magnesium within clay particles. Those minerals allow ion exchange processes to occur and adsorb sodium in irrigated water, reducing air and water circulation and reducing soil permeability, making it dry and harmful to plants (Ali and Ali, 2018). Soils are alkaline if they have high concentrations of sodium and carbonate, while salty soils have high concentrations of sodium and chloride, which affect plant growth. This ratio is calculated by (Equation 2) based on Wilcox (1955).

$$SSP\% = \frac{(Na^+ + K^+) * 100}{Ca^{2+} + Mg^{2+} + Na^+ + K^+}, \text{ (meq/L)} \quad (2)$$

3.2.3. Magnesium Hazard (MH%)

Generally, magnesium hazard represents elevation of Mg^{2+} content relating to Ca^{2+} content (Al-Kubaisi et al., 2018). The equilibrium state in water is maintained by calcium and magnesium ions that are used to estimate the hazard of magnesium. Irrigated water is considered harmful to plants where the MH% exceeds 50% (Rina et al., 2013). This ratio can be expressed by (Equation 3) according to Szabolcs and Darab (1964).

$$MH\% = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} * 100, \text{ (meq/L)} \quad (3)$$

3.2.4. Kelly's Ratio (KR)

It measures the sodium content of calcium and magnesium in the water (Chaudhary and Satheeshkumar, 2018), and it is determined by two classes: more and less than 1.

The first class indicates the high content of sodium and unsuitable irrigated water, whereas suitable irrigated water can be described as other types where KR is less than 1. It was obtained from (Equation 4) by Kelly (1946).

$$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}}, \text{ (meq/L)} \quad (4)$$

4. Results and Discussion

4.1. Data Quality

Relative differences or ionic balance error (IBE) is a measure applied in hydrochemistry work to assess the quality and accuracy of chemical analyses in sampled water. According to Appelo and Postma (1999), it is calculated by comparing the sum of the concentrations of cations (positively charged ions) to the sum of the concentrations of anions (negatively charged ions) as a percentage in meq/L in water. A small ionic balance error indicates that the sums of cations and anions are nearly equal, suggesting that the chemical analysis is accurate. Conversely, a large error may indicate problems with the analysis. It is an important quality control measure to ensure data reliability in hydrochemical studies.

The accepted limit of IBE lies between -5 to +5 %, where the results indicated that 83.3% of the sampled water had good data quality. In contrast, the 5-10 % limit represents 17% of sampled water. No samples scored poor data quality of more than 10 %. Therefore, the data is considered highly accurate for employment to enable the objective of the current study (Table 1). The IBE and Accuracy are described in Equations (5 and 6) respectively.

$$IBE = \frac{\sum Cations - \sum Anions}{\sum Cations + \sum Anions} * 100, \quad (5)$$

$$Accuracy = 100 - IBE, \quad (6)$$

Table 1. The ionic balance error of groundwater samples and its accuracy

Well	Y(DMS)	X(DMS)	SUM-C	SUM-A	IBE	Accuracy
1L	30°14'25.3"	47°47'02.0"	60.813	57.329	+3	97
2L	30°13'33.40"	47°46'32.4"	53.401	56.447	-3	97
3L	30°11'32.0"	47°49'38.1"	241.160	225.870	+3	97
4L	30°09'44.4"	47°49'42.1"	113.61	109.860	+2	98
5L	30°03'17.2"	47°54'30.0"	270.930	238.030	+6	94
6L	30°01'52.9"	47°56'02.7"	208.360	208.020	0	100
7L	30°01'49.1"	47°55'14.2"	119.210	103.320	+7	93
8L	30°02'15.3"	47°54'41.8"	85.7960	87.031	-1	99
9L	30°03'32.9"	47°54'44.6"	286.530	261.91	+4	96
10L	30°03'53.8"	47°53'32.3"	281.470	260.27	+4	96
11L	30°05'22.4"	47°49'55.2"	145.8	131.670	+5	95
12L	30°06'57.7"	47°42'30.5"	138.680	144.780	-2	98

4.2. The Spatial Distribution of Physicochemical Parameters

The spatial distribution of physicochemical parameters is explained in Fig.2. Generally, the southeast part of the studied area shows higher levels of most parameters such as E_c , TDS, TH, Ca^{2+} , Mg^{2+} , Na^+ , Cl^- , SO_4^{2-} , and HCO_3^- . The pH values ranged from 7.08-7.79, showing that the area studied has about a minimum alkalinity. The elevated pH in the northern parts may be due to the heavy sewage that drains into the Shatt al Basrah canal, and the lack of rain increases the contamination of the canal. The E_c is the measure of water solubility of ions, and it ranges from 4620-20200 μ S/cm. The highest levels of E_c are due to water rock interaction in the aquifer (Al-Suhail and Al-Mansory, 2003), and groundwater salinity is affected too by overproduction that leads to the movement of seawater through sediments of the Arabian Gulf (Jassim and Goff, 2006). The TDS ranged from 2958-12925mg/L. The limitation of increasing salinity with groundwater movement was intermittent flooding, recharge, and discharge areas, which were affected by the groundwater zones and the Jojob layer (Alkubaisi, 1996). The variation in E_c and TDS can be attributed to the lithological and mineralogical contents of Dibdibba formation or factors responsible for sedimentation and dissolution of different minerals (Al-Aboodi et al., 2008). The TH ranged from 1898-6347mg/L. It depends on the presence of Ca^{2+} and Mg^{2+} contents as calcium carbonate ($CaCO_3$). The hardness can be categorized as permanent and temporary. Permanent hardness is characterized by the presence of Ca^{2+} , SO_4^{2-} , and $MgCl$, treated by ion exchange. The temporary hardness is characterized by $CaCO_3$ or Mg^{2+} , which can be removed by boiling water (Kumar et al., 2014). The Ca^{2+} values range from 381-1273mg/L and originate from the dissolution of carbonate rocks such as limestone ($CaCO_3$) and dolomite $CaMg(CO_3)_2$. The Mg^{2+} ranged from 230- 770 mg/L, which results from the dissolution of dolomite and silicate weathering and seawater intrusion due to high concentrations of magnesium in the seawater (Kumar et al., 2014). The High concentrations of Ca^{2+} and Mg^{2+} are dominant due to the dissolution of carbonate minerals, where the groundwater can dissolve $CaMg(CO_3)_2$ and $CaCO_3$ present in the rocks and thus increase Ca^{2+} and Mg^{2+} concentration in water (Khwedim et al., 2017). Also, Mg^{2+} probably increases from Mg-rich clays such as palygorskite and chlorite as well as mafic minerals transported from the Arabian Shield (Alkinani and Merkel, 2017). The Na^+ ranged from 301-3662mg/L. The high content of Na^+ is due to the dissolution of Halite and weathering of silicate rocks bearing Na^+ , as well as the over-pumping of well water close to coastal areas under the influence of seawater intrusion (Kumar et al., 2014). The K^+ ranged from 7.11-41.9mg/L, the alkali metal originating from the decomposition process of sylvite mineral (as KCl), and clay minerals, potash feldspar orthoclase microcline. The content of fertilizers and decomposition of animals or waste are other sources of potassium that are concentrated in groundwater. Those Na^+ and K^+ are concentrated in the deposits of Dibdibba formation that resulted from igneous rocks in the Arabian Shield and transported in the sedimentation basin. The Cl^- ranged from 596-4632mg/L. Different sources lead to high levels of Cl^- in groundwater involving the dissolution of Halite, seawater captured within sediments, and anthropogenic genesis (Eyankware, 2020). The SO_4^{2-} ranged from 1693-6125mg/L. It comes from the dissolution of gypsum ($CaSO_4 \cdot 2H_2O$), intrusion of seawater (Jayathunga, 2020), and anthropogenic activity as fertilizers (Sharma and Kumar, 2020). The NO_3^- ranged from 0.62-1.76mg/L; a high level of NO_3^- results from extensive use of nitrogen fertilizers, leaky sewers, pit latrines, and high evaporation rates (Alkinani and Merkel, 2017). The HCO_3^- ranged from 92-451mg/L. It can originate from organic matter through the oxidation process, which produces carbon dioxide, fossils of carbonate rocks of limestone and dolomite, and the dissolution of silicate minerals through the weathering process (Xu et al., 2019).

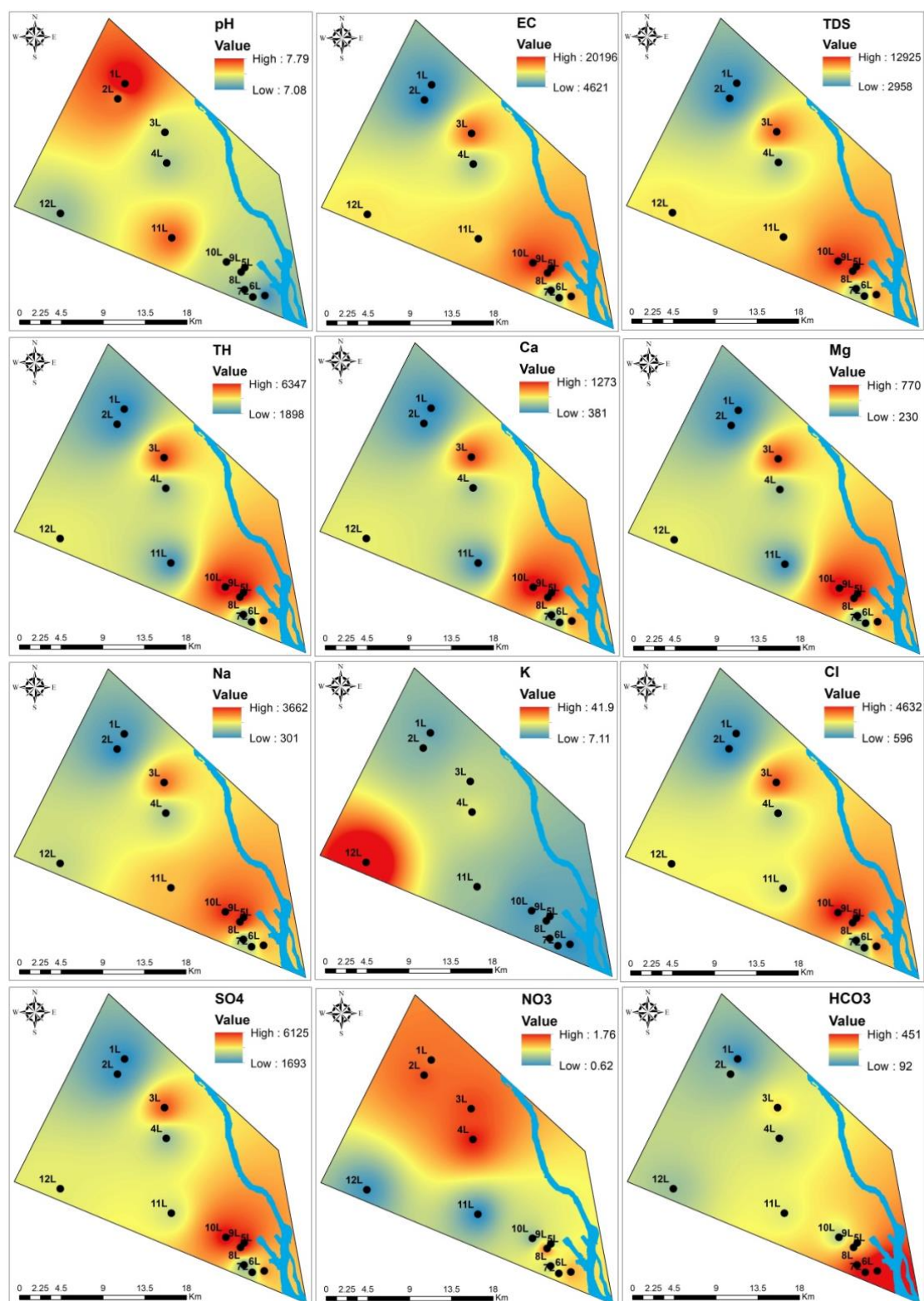


Fig.2. The spatial distribution of physicochemical elements based on IDW technique

4.3. Drinking Water Quality

A tabular comparison was made between the sampled water's physicochemical values and standard drinking water guidelines recommended by Iraqi Quality Standard limits (IQS, 2009) and the World Health Organization (WHO, 2017). The percentage of sampled water within the permissible limit is shown in (Table 2). 100% of sampled water within permissible limits for pH, 50% of sampled water

within permissible limits for K^+ , and 50% and 1% of sampled water within permissible limits for HCO_3^- by IQS and WHO standard guidelines, respectively. Other concentrations had largely exceeded the permissible limits. Generally, all the sampled water within the studied area is inappropriate for drinking.

Table 2. The statistics of physicochemical parameters compared to standard tables of IQS and WHO

Parameters	Min-Max	Mean-Median	R.D	IQS, 2009	WHO, 2017	Samples%
pH	7.08-7.79	7.35-7.28	0.201	6.5-8.5	8.5	100%
EC(μ S/cm)	4620-20200	13040-13325	5791.5	1500	1000	exceed
TDS(mg/L)	2958-12925	8345.6-8528	3706.6	1000	500	exceed
TH(mg/L)	1898-6347	3904.4-3319.7	1764.7	500	-	exceed
Ca ²⁺ (mg/L)	381-1275	784.83-667	353.4	75	75	exceed
Mg ²⁺ (mg/L)	230-770	472.6-402	214.4	125	50	exceed
Na ⁺ (mg/L)	301-3662	2040.3-1934	1231.1	200	200	exceed
K ⁺ (mg/L)	7.1-41.9	13.7-10.4	9.4	12	12	50%
Cl(mg/L)	595.5-4632	2614.8-2283.9	1519.4	250	250	exceed
SO ₄ ²⁻ (mg/L)	1693-6125	3820.3-3408.5	1663.3	250	200	exceed
NO ₃ ⁻ (mg/L)	0.62-1.76	1.24-1.32	0.42	50	50	100%
HCO ₃ ⁻ (mg/L)	91.5-451.4	227.5-207.3	100.6	200	120	50%(IQS) 1%(WHO)

4.4. Irrigation Water Quality

The spatial distribution of irrigation indices is clarified in (Fig.3). The SAR ranged from 2.93-23.15, the SSP from 25.09-71.98, the MH from 49.35-49.94, and the KR from 0.33-2.56. Extremely high levels of all indices are concentrated in the south and southwest parts of the studied area. Groundwater samples plotted to USSS Salinity diagram (Wilcox) suggested by Regional Salinity Laboratory U. S. in 1954 between electric conductivity as salinity hazard and SAR as Sodium hazard using AquaChem software (version 10.0) as shown in (Fig.4). About ten samples (83.3 %) fall in very high salinity-very high sodium hazard class (C_4S_4), the rest of two samples (16.7%) fall in very high salinity-high sodium hazard class (C_4S_3) and very high salinity-medium sodium hazard class (C_4S_2), respectively.

All values of irrigation indices and the statistical values are shown in Table 3. The suitability of irrigated water can be observed in Table 4, where SAR can be categorized into four water classes according to Richard (1954): excellent, less than 10; good, from 10-18; doubtful, from 18-26; and unsuitable, more than 26. The results of SAR declared that 25%, 41.7%, and 33.3% indicated excellent, good, and doubtful water classes, respectively. Wilcox (1955) divided the SSP values into five water classes: excellent, less than 20; reasonable, from 20-40; permissible, from 40-60; doubtful, 60-80; and unsuitable, more than 80. The SSP values scored 16.7%, 75%, and 8.3% of sampled water belonging to good, permissible, and doubtful water classes, respectively. Neither excellent nor unsuitable water classes have been observed in sampled water regarding SSP% calculations. According to Szabolcs and Darab (1964), only two water classes represent the MH values: suitable water for MH is more than 50, and unsuitable water for MH is less than 50. All water samples within the area studied are suitable as irrigated water concerning MH%. As with the same MH classification, Kelly (1946) categorized water into two types, suitable and unsuitable for KR more than 1 and less than 1, respectively. According to the KR division, about 41.7% of sampled water is suitable water, and the rest of the 58.3% represents unsuitable water for irrigation where KR values scored more than 1.

4.5. The Impact of Increased Irrigation

The impact of increased irrigation for agriculture can exacerbate groundwater quality issues. When large volumes of water are withdrawn, it can lower the water table, increasing the risk of saltwater intrusion in coastal areas. Additionally, agricultural practices that rely heavily on fertilizers and pesticides can contribute to groundwater contamination if these chemicals are not adequately managed.

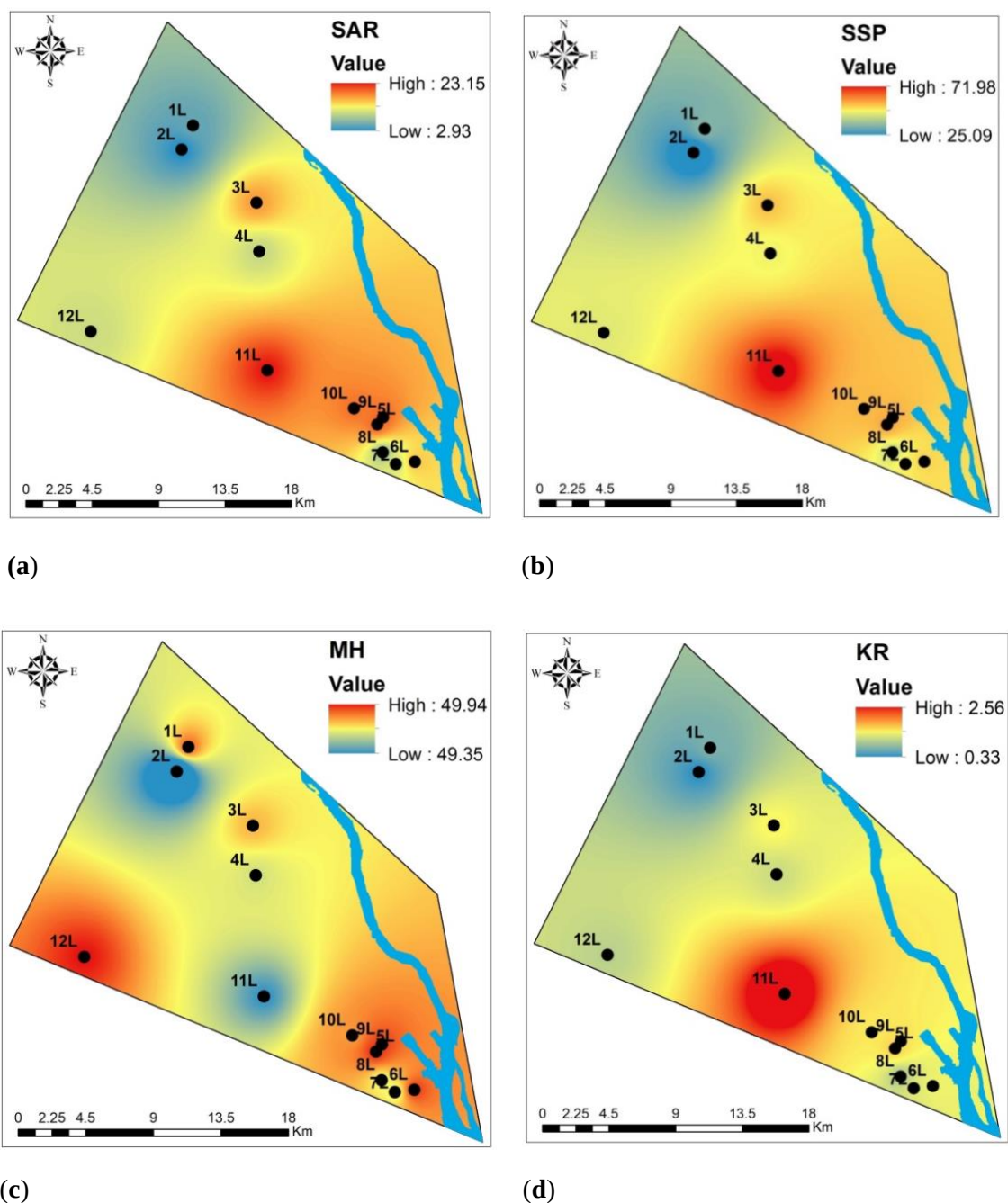


Fig.3. The spatial distribution of irrigation indices based on IDW technique

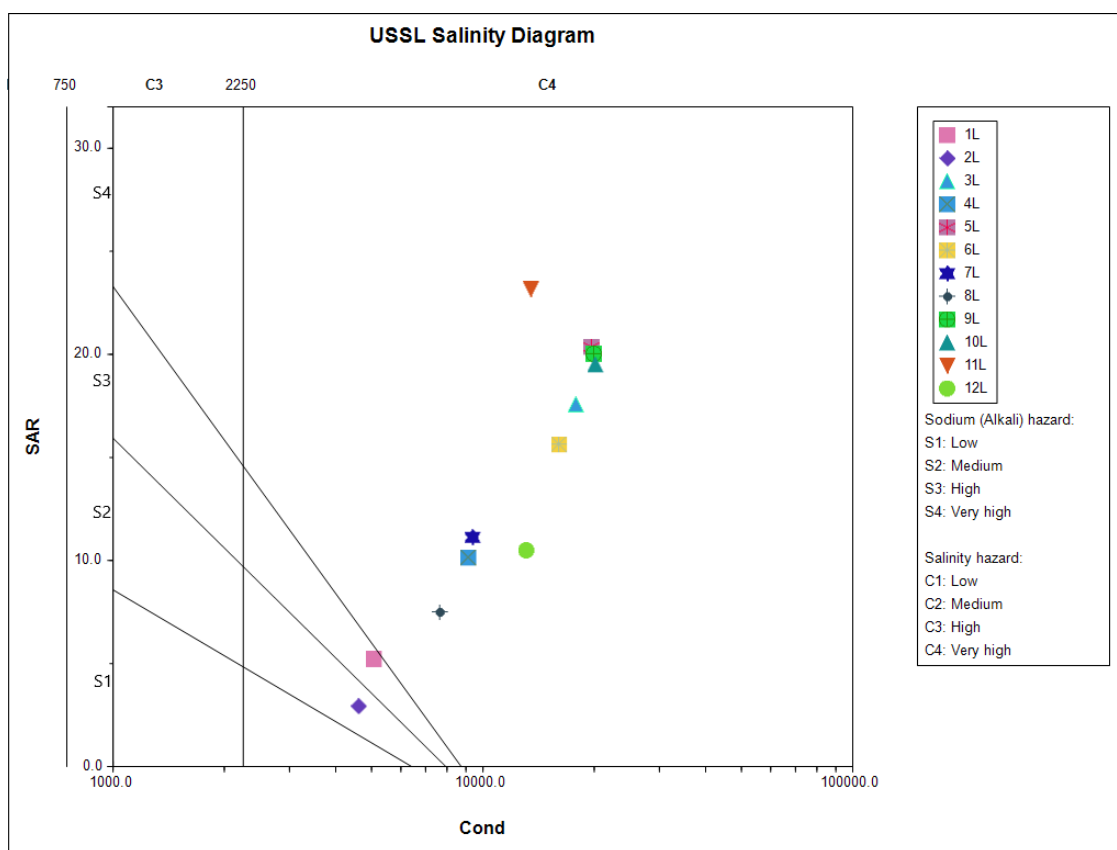


Fig.4. USSS Salinity Diagram (Wilcox) of groundwater samples by AquaChem software

Table 3. The values of irrigation indices and statistics of water samples

Well	SAR	SSP	MH	KR
1L	5.19	37.62	49.88	0.596
2L	2.93	25.08	49.35	0.327
3L	17.56	54.24	49.80	1.18
4L	10.12	48.569	49.698	0.94
5L	20.35	57.25	49.93	1.34
6L	15.62	52.70	49.90	1.11
7L	11.12	50.719	49.71	1.03
8L	7.48	43.31	49.73	0.76
9L	20.003	55.7	49.91	1.26
10L	19.498	55.13	49.82	1.23
11L	23.15	71.99	49.54	2.56
12L	10.465	46.67	49.94	0.86
Min	2.93	25.083	49.354	0.327
Max	23.15	71.986	49.938	2.56
Mean	13.624	49.915	49.77	1.098
Median	13.367	51.711	49.813	1.069
S.D	6.622	11.492	0.177	0.547

Table 4. Water class of samples according to the standard level of irrigation indices

Indices	Range	Water Class	Values	Samples No.	Samples %
SAR	<10	Excellent	2.93-7.48	3	25 %
SAR	10-18	Good	10.12-17.56	5	41.7 %
SAR	18-26	Doubtful	19.5-23.15	4	33.3 %
SAR	>26	Unsuitable	Nil	nil	Nil
SSP	<20	Excellent	Nil	nil	Nil
SSP	20-40	Good	25.08-37.62	2	16.7%
SSP	40-60	Permissible	43.31-57.25	9	75%
SSP	60-80	Doubtful	71.99	1	8.3
SSP	>80	Unsuitable	Nil	nil	Nil
MH	<50	Suitable	49.35-49.94	all	100%
MH	>50	Unsuitable	Nil	nil	Nil
KR	<1	Suitable	0.33-0.86	5	41.7
KR	>1	Unsuitable	1.03-2.56	7	58.3

5. Conclusions

Groundwater is an important source in the south part of Basrah, south of Iraq, due to inevitably irreplaceable for various activities, large harbors, more farms and plantations, petrochemical and fertilizers industrials, ice factories, and water desalination plants. This study aims to assess the drinking and irrigation water quality through physicochemical analyses. According to standard guidelines of IQS, 2009 and WHO, 2017, all twelve sampled waters are inappropriate for drinking supply because most parameters exceeded the permissible limits except pH and NO_3 . According to irrigation indices, SAR indicated that 25% to 41.7% of sampled water is excellent to good irrigated water, respectively. SSP results showed that 16.7% to 75% of sampled water is good to permissible irrigated water. KR concluded that 41.7% of sampled water is suitable for irrigated water. The previous excellent, good, permissible, and suitably irrigated water is concentrated in the area's northern and northwestern parts studied. The MH indicated that all water samples within the area studied are almost suitable for irrigation, but they are close to a hazardous degree. The southern and southeastern parts showed that 33.3% and 8.3% are doubtful irrigated water from the results of SAR and SSP, respectively. Meanwhile, KR results showed that 58.3% of the sampled water was unsuitable for irrigation. The bad quality of groundwater is mainly caused by high salinity due to the increasing total dissolved solids. Excessive pumping of groundwater can lead to saltwater intrusion in coastal aquifers. Human activities and agricultural procedures that largely depend on fertilizers and pesticides can impact the natural flow of groundwater and contribute to salinity. Several strategies to mitigate the risk of high salinity in groundwater require careful planning and management: Reducing pumping rates, constructing subsurface barriers that can prevent saltwater from moving inland, and artificial recharge by injecting freshwater into aquifers.

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