Assessment of Ground Water Quality for Drinking and Agricultural Uses in Mouqdadiya District, Diyala, Iraq

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ABSTRACT

In order to evaluate the quality of ground water in Al-Mouqdadiya District, Diyala, Iraq, ground water samples were collected from 15 wells in the summer and winter seasons of 2012 and analyzed for various parameters. Physical and chemical parameters of groundwater including electrical conductivity, pH, TDS, Na, K, Ca, Mg, Cl, HCO_3, NO_3 and heavy metals (Cd, Fe, Pb, Mn, Zn) were determined. Irrigation indices such as, Sodium Absorption Ratio (SAR), Soluble Sodium Percentage (SSP), Residual Sodium Carbonate (RSC), Permeability Index (PI) and Magnesium Hazard (MH) were calculated. Based on the observed results, the TDS of ground water in the study area exceeded the Iraqi guideline for drinking water in 47% while this ground water falls generally in the category of very hard (TH>300 mg/L). For Ca, Mg, Cl, Cd, Pb and Mn it can be concluded with some exception most of the ground water sample were observed to be above of the Iraqi guideline for drinking water. According to the SAR values most of the ground water samples are belong to slight to moderate to severe degree of restriction on use. While the calculated vales of SSP indicated low degree of restriction on the use of this ground water in irrigation. However, the ground water in the study area can be selected as Class III (with 25% maximum permeability) water, which are unsuitable for irrigation purposes according the Permeability and magnesium hazard indices.

Keywords: Ground Water Quality, SAR, RSC, Irrigation, Iraq

تقييم نوعية المياه الجوفية للشرب والاستخدام الزراعي في منطقة المقدادية، ديالى، العراق

الخلاصة

من أجل تقييم نوعية المياه الجوفية في منطقة المقدادية، ديالى، العراق، تم جمع عينات المياه الجوفية من 15 بئر في فصلي الصيف والشتاء من عام 2012 وتم تحليل المتغيرات الفيزيائية

والكيميائية (التوصيلية الكهربائية، الدالة الحامضية، المواد الصلبة الذائبة، الصوديوم، البوتاسيوم، الكالسيوم، المغنيسيوم، الكلورايد، البيكاربونات والنترات) والمعادن الثقيلة (الكادميوم، الحديد، الرصاص، المنغنيز والزنك). تم حساب مؤشرات الري مثل نسبة امتزاز الصوديوم (SAR)، نسبة الصوديوم القابلة للذوبان (SSP)، كربونات الصوديوم المتبقية (RSC)، مؤشر نفاذية (PI) وخطورة المغنيسيوم (MH). لوحظ ان قيم المواد الصلبة الذائبة في المياه الجوفية في منطقة الدراسة تجاوزت قيم المواصفة العراقية لمياه الشرب في 47٪ في حين أن هذه المياه الجوفية تقع في فئة المياه العسرة جدا (TH > 300 ملغم / لتر). كما اوضحت النتائج ان قيم تركيز الكالسيوم والمغنيسيوم والكلور والكادميوم والرصاص والمنغنيز تجاوزت مع بعض الاستثناءات قيم المواصفة العراقية لمياه الشرب. ووفقا لقيم SAR فان معظم عينات المياه الجوفية تصنف ضمن صنف المياه ذات المشاكل الحادة اومشاكل خفيفة الى متوسطة في استخدام هذه النوعية من المياه في الري. في حين أن القيم المحسوبة لـ SSP أشارت انخفاض درجة القيود في استخدام هذه المياه في الري. ومع ذلك، فإن المياه الجوفية في منطقة الدراسة يمكن اعتبارها من الدرجة الثالثة (مع 25 ٪ كحد أقصى نفاذية) المياه، والتي تعد غير مناسبة لأغراض الري وفقا للنفاذية ومؤشر خطورة المغنيسيوم.

INTRODUCTION

The sustainable development in Iraq is being hindered by several obstacles. Water, being related to the food security, is a main concern that could duplicate the already present socio-economic dilemmas [1]. However, the monitoring of water quality is one of the important tools for sustainable development and provides important information for water management [2]. Quality of ground water is similarly important to its quantity owing to the suitability of water for various purposes. Furthermore, water quality monitoring and analysis is an important subject in ground water studies [3,4,5].

Water quality may differ depending upon variations in geological formations and human activities such as extreme agricultural and urbanization [5,6].

The chemical alteration of the ground water depends on several factors, such as interaction with solid phases, residence time of ground water, seepage of polluted river water, mixing of ground water with pockets of saline water and anthropogenic impacts [7].

Anthropogenic activities like explosion of population, industrial growth, inputs of fertilizer, pesticides, and irrigation have been a crucial factor for determining the quality of ground water.

Agricultural activities, urban growth and a lack of water resources caused a high demand on a ground water in arid and semi-arid regions of Iraq and putting this resource at greater risk of contamination.

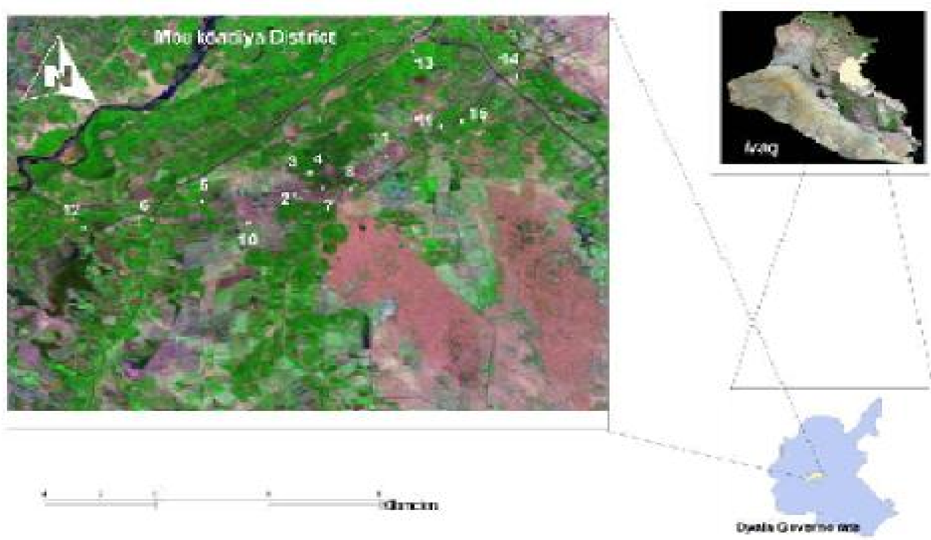
The importance of availability of water with good quality for human health has recently involved a great deal of interest. It is noted that ground water is an important water resource for drinking and agriculture uses in study area. Therefore, the current research is attempted to evaluate the suitability of ground water of Al-Muqdadiya district for drinking and agricultural uses, using GIS program, chemical relations and equations in order to estimate the suitability of ground water for drinking and irrigation uses.

Materials and Methods

Al-Muqdadiya is a city in the Diyala Governorate which is located at eastern part of Iraq. The city is located between latitudes 33° 39' – 34° 06' North' and longitudes

44^{o} $42^{'}$– 45^{o} $15^{'}$ East, about 80 km northeast of Baghdad and 30 km northeast of Baquba, the capital of Diyala and covers an area of 1033 square kilometers.
Fifteen sites (Figure 1), primarily engaged in agriculture as the main human activities, were selected for this study. The sites included Al-Arabi (sample No.1), Hay Al-Ashbal (2), 17-July (3), Hay Al-Moalmeen (4), Al-Akmar (5), Abo-Hasewah (6), Hay Al-Assry (7), Hay Al-Shuhdaa (8), Abu-Jessreh (9), Hay Al-Askary (10), Dhaia Washaa (11), Rukbah (12), Tawakul (13), Al-Harwnai (14) and Shuk Al-Reem.
Characterized soil Muqdadiya being part of soils alluvial plain deposits of Quaternary talk, conveyed by the Diyala River (which is a tributary of the Tigris River) by factors deposition time floods, which made it the most fertile alluvial plain soils because of its organic materials, metal and alluvial sand and good drainage.

Fifty four ground water samples were collected in polyethylene bottles during winter (January) and summer (July) of 2012 to cover the seasonal variations. Rest of the characteristics of water samples were immediately analyzed in the laboratory after transportation to the Environmental Research Center, University of Technology, Baghdad. High pure chemicals and double distilled water were used for preparing solutions for analysis. The pH and Electrical Conductivity (EC) were measured using pH-EC meters. Procedures for selected ground water constituents followed for analysis have been in accordance with the Standard Methods for Examination of Water and West water [8].



Figure(1): Map of the study area and ground water sampling locations

Quality data was checked by ionic balance, which is an important assessment for data quality. It gives an indication of the quality of analysis as well as the possibility of any missing parameter. The data were rejected if they did not meet the quality criteria. The test is based on the difference percentage defined as:

$$\% \text{ difference} = 100 \frac{\left|\sum \text{cations} - \sum \text{anions}\right|}{\sum \text{cations} + \sum \text{anions}} \qquad \ldots(1)$$

The anion and cation sums are expressed as milliequivelents per liter and the typical criteria for acceptance is 5% for anion sum (10.0–800 meq/L) [8].

Results and Discussion

An extended module of ArcGIS 3.2 was used to find out the spatiotemporal behavior of the ground water quality parameters. Ground water quality classification maps for pH, EC, TDS, TH, Cl, HCO_3, Ca, Mg, K, Na NO_3 and heavy metals (Cd, Fe, Pb, Mn, Zn) from thematic layers, based on the Iraqi standards for drinking water, have been formed for Al-Mouqdadiya District.

pH of water is an important indication of its quality and provides information in many types of geochemical equilibrium or solubility calculations [9]. All the ground water samples are falling in the range of 6.5 to 7.4 (Figure 2). However, the observed values of pH of the ground water are within the permissible limits of Iraq drinking water standard [10] and recommended value for irrigation where the normal pH range for irrigation water is from 6.5 to 8.4 [11]. Irrigation water with a pH outside the normal range may cause a nutritional imbalance or may contain toxic ion [12,13].
TDS is an indicator of the overall suitability of water for domestic use. TDS quality guideline for drinking water in Iraq is ≤ 1000 mg/L [10]. TDS distribution map shows that the freshwater (<1,000 mg/L) is dominant in the north east parts of the study area (Figure 3). The salinity increases gradually in all directions. Increasing of salinity to the south west is mostly due to low ground water recharge. However, the TDS levels exceeded by 47% the values of the Iraqi guideline for drinking water.

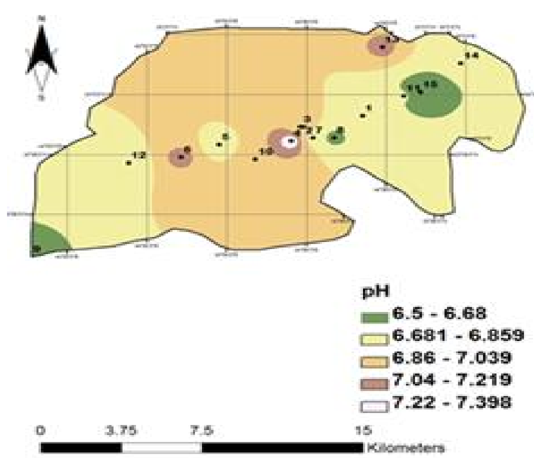


Figure (2): Spatial distribution of pH in the study area

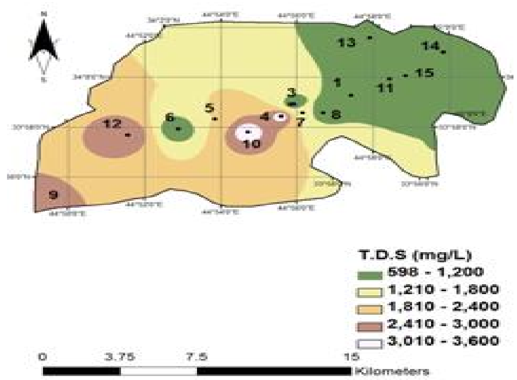


Figure (3): Spatial distribution of TDS in the study area

Electrical conductivity (EC) is the most important parameter in determining the suitability of water for irrigation use and it is a good measurement of salinity hazard to crop. The spatial patterns of water electrical conductivity are illustrated in Figure 4. Slight to moderate degree of restriction on the use of this ground water in irrigation in the south west part of study area can be shown due to salt build-up in soils and its adverse effects on plant growth [14]. Furthermore, the results indicted also that this type of ground water can be used on the soils with controlled drainage. However, irrigation water with conductivity in the range of 0.75-2.25 mS/cm is acceptable for irrigation and widely used.

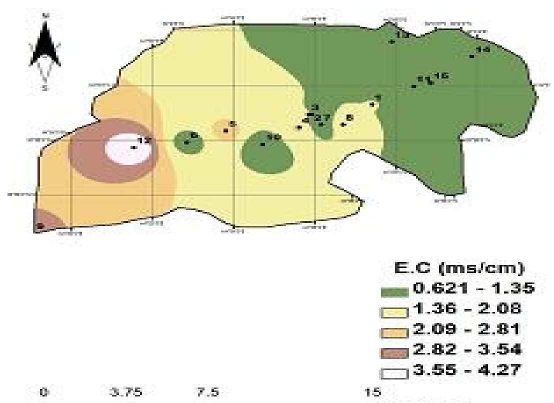


Figure (4): Spatial distribution of EC in the study area

The hardness quality guideline for drinking water in Iraq is 500 mg/L. The spatial patterns of water hardness are illustrated in Figure 5. It can be noted that most of ground water in the study area have hardness values above the Iraqi standard. Hard water is not a direct health hazard but it is a nuisance to consumers. Hard water can cause scaling problems in the plumbing fixtures and household appliances, increase soap consumption and form unsightly soap scums or films [15]. However, according to the TH classification [16], all the ground water samples fall in the category of very hard (>300 mg/L).

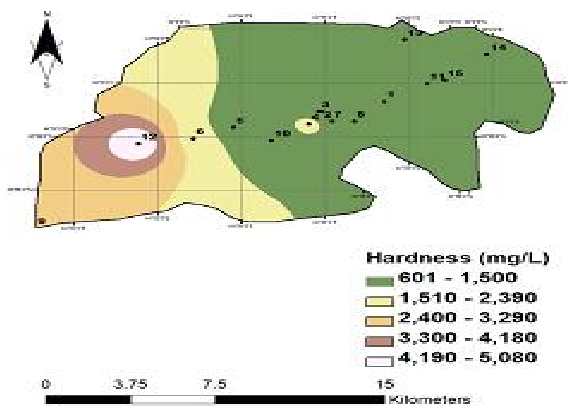


Figure (5): Spatial distribution of hardness in the study area

Calcium concentration ranges between 81.76 and 292.58 mg/L with an average of 147.65 mg/L in the summer season (Figure 6), and ranges between 46.9 mg/L and 915.34 mg/L with an average of 319.9 mg/L. With few exception in the winter season most of the calcium content in the study area are well above the permissible limits of Iraq drinking water [11]. Calcite, dolomite and gypsum are responsible for enriching the ground water with calcium ions [18].

The magnesium concentration in the ground water samples ranges between 125.93 to 1177.95 mg/L an average of 342.29 mg/L in the summer season, and ranges between 45.61 to 264.55 mg/L with an average of 133.28 mg/L in the winter season (Figure 7). The Iraqi drinking water standard has less than 50 mg/L Mg. Increasing of Mg may be due to continuous weathering of aquifer materials [18].

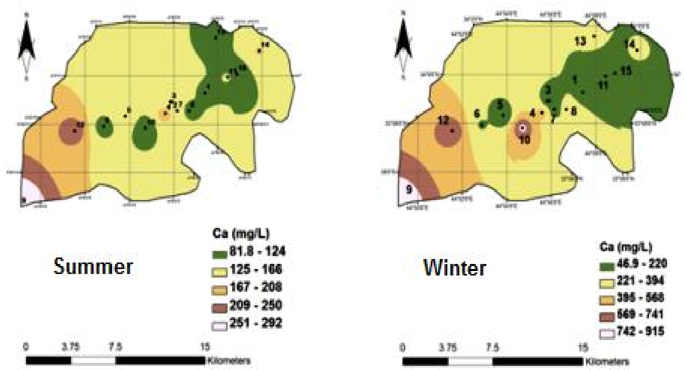


Figure (6): Spatial distribution of Ca concentration in the study area

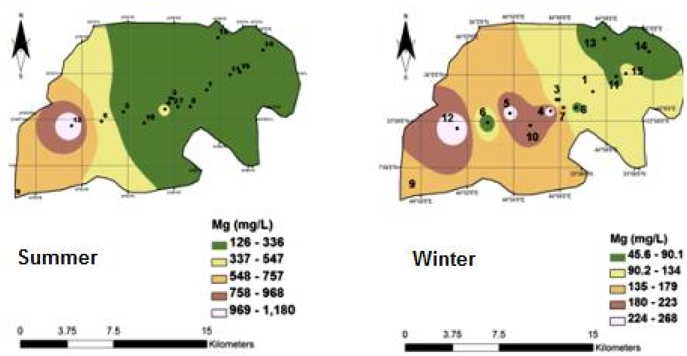


Figure (7): Spatial distribution of Mg concentration in the study area

Sodium is directly related to salinity content of the ground water. The concentration of sodium increases south west in summer season while sodium concentration increased in the middle part of the study area (Figure 8). Most of the ground water samples fall within the permissible limit of Iraqi drinking water standard [10]. Furthermore, sodium concentrations in the ground water samples varied from 25.77 to 129.62 mg/L with an average value of 79.08 mg/L in the summer season, while the concentration of sodium varied from 30.17 to 269.18 mg/L with an average value of 102.3 mg/Lin the winter season, indicating non to slight to moderate degree of restriction for sensitive crops on the use of this ground water in irrigation. Sodium content is the most troublesome of the major ions and an important factor in irrigation water quality evaluation. [11]. However, the water can be used for irrigation when the concentration of sodium is about 184.0 mg/L [19]. Excessive sodium leads to development of an alkaline soil that can cause soil physical problems and reducing soil permeability [20].

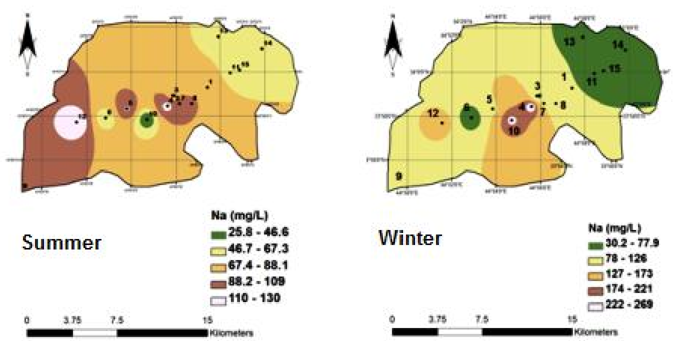


Figure (8): Spatial distribution of Na concentration in the study area

Chloride ion is a predominant natural form of chlorine and is extremely soluble in water. The major sources of chloride in natural water are sedimentary rocks particularly evaporates [21]. The limit for drinking purposes is fixed at 250 mg/L [10]. In the present study (Figure 9) chloride ion content in all the ground water samples varied from 238.2 to 2246 mg/L with an average value of 824.71 mg/L in the summer season, while the concentration of chloride varied from 49.98 to 369.88 mg/L with an average value of 131.62 mg/Lin the winter season, indicating moderate degree of restriction to unsuitable on the use of this ground water in irrigation [11].
The concentration of HCO_3 ion found in the ground water samples of study area is ranged from 4.88 to 56.14 mg/L with an average of 29.78 mg/L in the summer season, and from 0.43 to 1.29 mg/L with an average of 0.78 mg/L in the winter season (Figure 10).

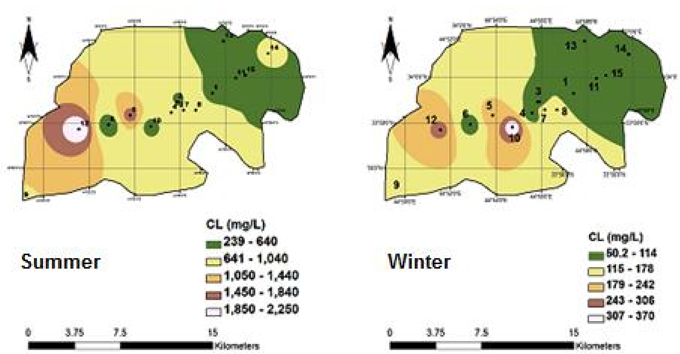


Figure (9): Spatial distribution of Cl concentration in the study area

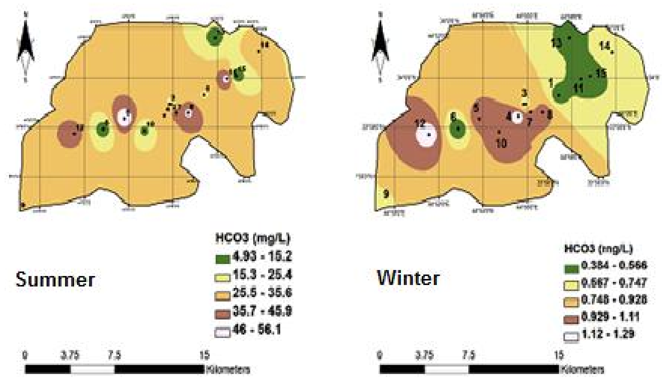


Figure (10): Spatial distribution of HCO_3 concentration in the study area

The nitrate concentration in the groundwater samples range from 6.2 to 52.27 mg/L with an average of 17.78 in the summer season, and from 5.31 to 117.83 mg/L with an average of 20.88 mg/L in the winter season. The source of nitrate in area is nitrogen fertilizers (commonly urea, nitrate or ammonium compounds) that are used for agricultural practices. NO_3 quality guideline for drinking water in Iraq is $\leq$ 50 mg/L [10]. NO_3 distribution map show that the freshwater (<50 mg/L of NO_3) is dominant in the most parts of the study area (Figure 11).

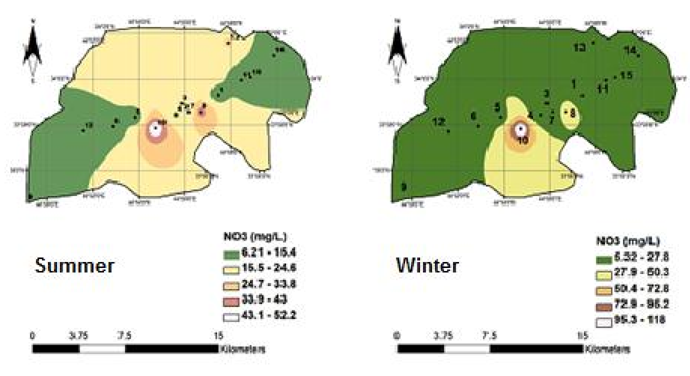


Figure (11): Spatial distribution of NO_3 concentration in the study area

The concentrations of cadmium displayed in the study area ranged from 0.0315 to 0.0541 mg/L with an average of 0.043 mg/L in the summer season, while it ranged from not detectable to 0.0028 mg/L with an average of 0.0011 mg/L in the winter season (Figure 12). However, the observed cadmium concentrations in the summer season are above 0.003 mg/L which is considered as the Iraqi drinking water standard limit [10]. With some exception of the cadmium concentrations in the winter season it can be noted that that the higher observed value were recorded in the northeast and southwest part of the study area since the groundwater pH in these parts is lower; it increases the solubility of Cd [22].

The observed Zn and Fe concentrations in the study area were below the Iraqi drinking water standard limit (Figure 13 and 14).

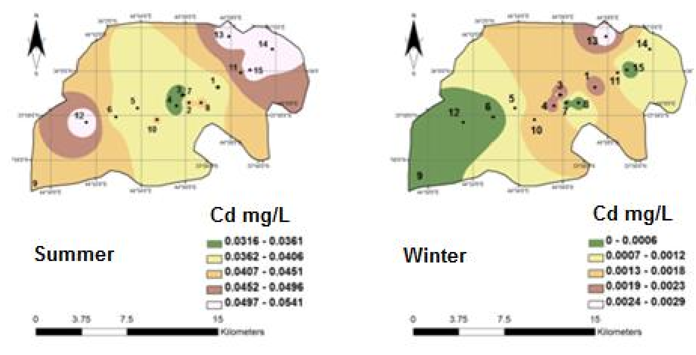


Figure (12): Spatial distribution of Cd concentration in the study area

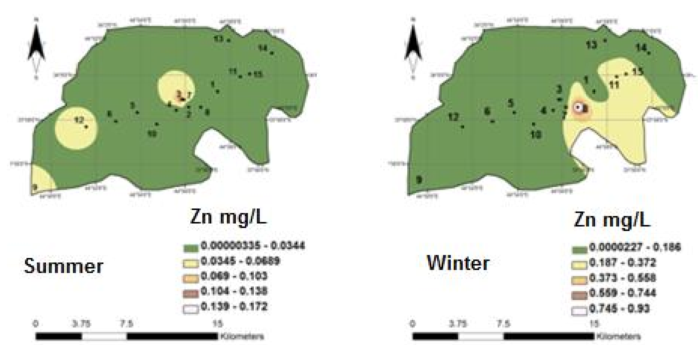


Figure (13): Spatial distribution of Zn concentration in the study area

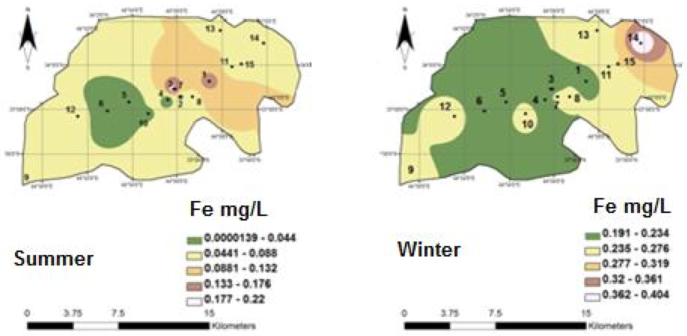


Figure (14): Spatial distribution of Fe concentration in the study area

Lead (Pb) has been known to be toxic to human. However, the observed concentrations of Pb in the all ground water samples (Figure 15) were high compared to the Iraqi drinking water standard limit [10]. This indicates that, the ground water samples were contaminated by Pb and affected by the migration of leachate to the ground water.

Similar to the Pb, manganese concentrations in the all ground water samples (Figure 15), were observed to higher compare to the Iraqi drinking water standard limit [10]. Manganese compounds exist naturally in the environment as solids in the soils and small particles in the water. Manganese that derives from human sources can also enter groundwater [23].

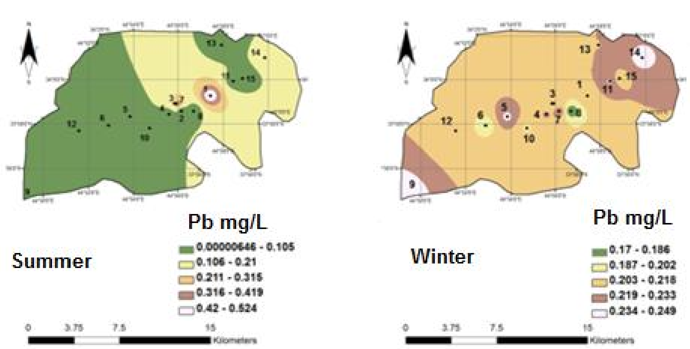


Figure (15): Spatial distribution of Pb concentration in the study area

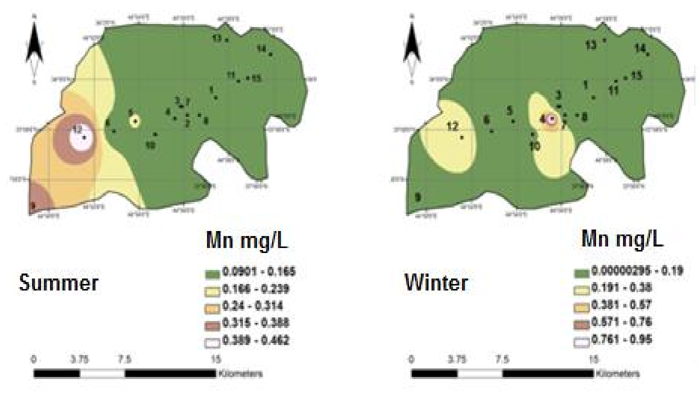


Figure (16): Spatial distribution of Mn concentration in the study area

Irrigation Indices

Indices such as, Sodium Absorption Ratio (SAR), Soluble Sodium Percentage (SSP), Residual Sodium Carbonate (RSC), Permeability Index (PI) and Magnesium Hazard (MH) are significant parameters for determining the suitability of ground water for agricultural purpose [24,25].

Sodium concentration plays a significant responsibility in evaluating the ground water quality for irrigation because sodium causes a reduction in the soil permeability. Sodium hazard of irrigation water can be well understood by SAR which determines its utility for agricultural uses.

Sodium Absorption Ratio (SAR) is defined by the following equation [26].

$$\textbf{SAR} = \frac{Na^{+}}{\sqrt{\dfrac{Ca^{2+} + Mg^{2+}}{2}}} \qquad \ldots (2)$$

where Na, Ca and Mg concentrations are expressed in meq/L.

The SAR values range from 0.63 in summer season to 0.87 in winter season and according to the Ayers and Westcot [11] classification of irrigation water based on SAR and EC values (Table 1), most of the ground water samples are belong to slight to moderate to severe degree of restriction on use.

Soluble Sodium Percentage (SSP), it is also used to assess sodium hazard. SSP was calculated by Eaton [27].

$$\text{SSP} = \frac{Na^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100 \qquad \ldots(3)$$

where all the ions are expressed in meq/L.

The calculated values of SSP varied from 10.11% in the summer season to 14.32% in the winter season representing low degree of restriction on the use of this ground water in irrigation [28].

Table (1): Classification of irrigation water based on SAR and EC values

Classification	Degree of restriction on use		
EC (mS/cm) & SAR	None	Slight to Moderate	Severe
If SAR 0-3 & EC	> 0.7	0.7-0.2	< 0.2
If SAR 3-6 & EC	> 0.2	0.2-0.3	< 0.3
If SAR 6-12 & EC	> 1.9	1.9-0.5	< 0.5
If SAR 12-20 & EC	> 2.9	2.9-1.3	< 1.3
If SAR 20-40 & EC	> 5.0	5.0-2.9	< 2.9

Residual sodium carbonate (RSC) has been used to determine the hazardous effect of carbonate and bicarbonate on the quality of water for irrigation. RSC is a calculated value expressing the excess in carbonate and bicarbonate content, which remains after the consumption of calcium and magnesium content. To qualify this effect an experimental parameter termed as RSC was calculated according to the equation recommended by Eaton [27] as follows:

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{+2}) \qquad \ldots (4)$$

where the ions are expressed in meq/L.

The irrigation water containing more than 2.5 meq/L of RSC is not suitable for irrigation, while irrigation water having 1.25-2.3 meq/L of RSC is permissible and water with less than 1.25 meq/L are good for irrigation. The calculated RSC values were (–34.96) in summer season and (-26.91) in winter season which indicated that majority of ground water samples irrespective of seasons have RSC less than zero and are good suitable for irrigation uses.

Soil permeability is affected by the long-term use of irrigation water and the influencing parameters are sodium, calcium, magnesium, bicarbonate and the soil type. Furthermore, the Permeability Index (PI) was also used for assessing sodium hazards and the suitability of water for agricultural use [29].

PI is calculated by the method suggested by Doneen [30].

$$PI = \frac{Na^{+} + \sqrt{HCO_3^{-}}}{Ca^{2+} + Mg^{2+} + Na^{+}} \times 100 \qquad \ldots (5)$$

where all the ions are expressed in meq/L.

The PI values in this study range from 11.23% in the summer season to 14.84% in the winter season. However, the ground water in the study area can be selected as Class

III (with 25% maximum permeability) water which are unsuitable for irrigation purposes.
One more indicator that can be used to identify the magnesium hazard (MH) is proposed by Szabolcs and Darab [31] for irrigation water and calculated as in the following formula:

$$MH = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100 \qquad \ldots(6)$$

where, Ca^{2+} and Mg^{2+} ions are expressed in meq/L.
The mean value of MH in the summer season is 75.61%, while in the winter season has been calculated as 43.67. It is reported that if the value of MH is less than 50, then the water is safe and suitable for irrigation [32]. However, the ground water can be classified with few exceptions as unsuitable for irrigation uses.

CONCLUSIONS

The results indicates that this ground water in the study area falls generally in the category of very hard (TH>300 mg/L). For Ca, Mg, Cl, Cd, Pb and Mn it can be concluded with some exception most of the ground water sample were observed to be above of the Iraqi guideline for drinking water. Irrigation indices such as, Sodium Absorption Ratio (SAR), Soluble Sodium Percentage (SSP), Residual Sodium Carbonate (RSC), Permeability Index (PI) and Magnesium Hazard (MH) were calculated were the indices employed in this study. The results indicate that most of the groundwater quality samples according to the SAR values are belong to slight to moderate to severe degree of restriction on use. While the calculated vales of SSP indicated low degree of restriction on the use of this ground water in irrigation. However, the ground water in the study area can be selected as Class III (with 25% maximum permeability) water, which are unsuitable for irrigation purposes according the Permeability and magnesium hazard indices.
This study recommends that the study area indicated with few exceptions by poor groundwater quality for human consumption. For irrigation this type of ground water can be used on the soils with controlled drainage, appropriate soil amendments should be applied on agricultural farmlands.

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