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# Application of GIS Technique to Evaluate the Groundwater Quality for Irrigation Purposes

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## Abstract

Geographic Information System (GIS) technique has been applied in the current study to produce irrigation water quality index (IWQI) map for the Karbala provenience in Iraq. For this purpose, hundred and twenty two (122) samples of groundwater have been collected for various sites of the study area. These samples have been analyzed for different elements that affect the irrigation water quality. Specifically, five chemicals parameters were used Electrical conductivity (EC), $Cl^-$, $HCO_3^{-1}$, Na% and Sodium Absorption Ratio (SAR) to create the database of water quality which has been transferred to the GIS platform to produce a spatial distribution map of each parameter using reverse interpolation technique (IDW). The results of these parameters were also used to calculate irrigation water quality index values, and transferred to the GIS platform for the production of the irrigation water quality index map. Accordingly the groundwater in the studied area is unsuitable for irrigation except for a small part which represents 8 % of the total area that could be used with high permeability soils, which have the ability to carry a high proportion of salts.

## Introduction

Groundwater is one of the main factors contributing to the expansion of the agricultural production in many countries. In the Republic of Iraq, groundwater is largely untapped because people generally use the river's water for agriculture and drinking purposes, especially in areas where population is close to these rivers. Recently, the demand for water has increased due to two factors; some neighboring countries like Turkey state have built dams in addition to the reduced rainfall, those factors have severely affected the river water quantity and quality in the republic of Iraq. Hence, the Iraqi supervision has drilled many wells, especially in remote areas of rivers for different uses. In the present study, 122 wells distributed in Karbala region were selected to evaluate water for irrigation using GIS technique by generating irrigation water quality index (IWQI) map. During earlier years researchers at the United States Salinity Laboratory (USSL) (1954) [1] and Wilcox (1954) [2] established the standards methods for assessing irrigation water. In the year of (2010) Meireles et al., [3] has develop IWQI model using the specific chemical parameters such as electrical conductivity, Magnesium Sodium Potassium Chloride, Bicarbonate and SAR for assessment of groundwater quality and identified its potential for irrigation purposes. Several workers in the world have applied IWQI model for evaluating the quality of water for irrigation use. Omran and Marwa (2015) [4], [5] and [6] have been integrated this index with GIS technique to assess the drainage water for irrigation. All those studies showed that this method can help to a better understanding and to decide about the status of the drainage water quality by summarizing the observation data or showing the spatial distribution of the quality index. The model has also used as a management tool by [7], [8] and [9] In the current study GIS technique has been used to generate IWQI map to evaluate the groundwater in the Karbala province which is located in central Iraq and to specify their potentiality for irrigation uses. The area under study is situated in the center of Iraq about 100 km south of Baghdad. It is bounded to the south by Najaf province, to the East and North East by Al-anbar province, to the west and North West by the province of Babel. It is bounded by latitudes 32°

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8' 00" to 32° 51' 00" North and longitude 34° 10' 00" to 44° 17' 00" East (Fig.1). Historically, the study area is considered one of the greatest holy cities to Muslims in general and Shiites in particular. The studied area is about 5,043 square kilometers and has a population of about 1.067 million (Jan 7, 2011). The climate of the study area is characterized by cold weather in winter with low precipitation and hot dry summers.

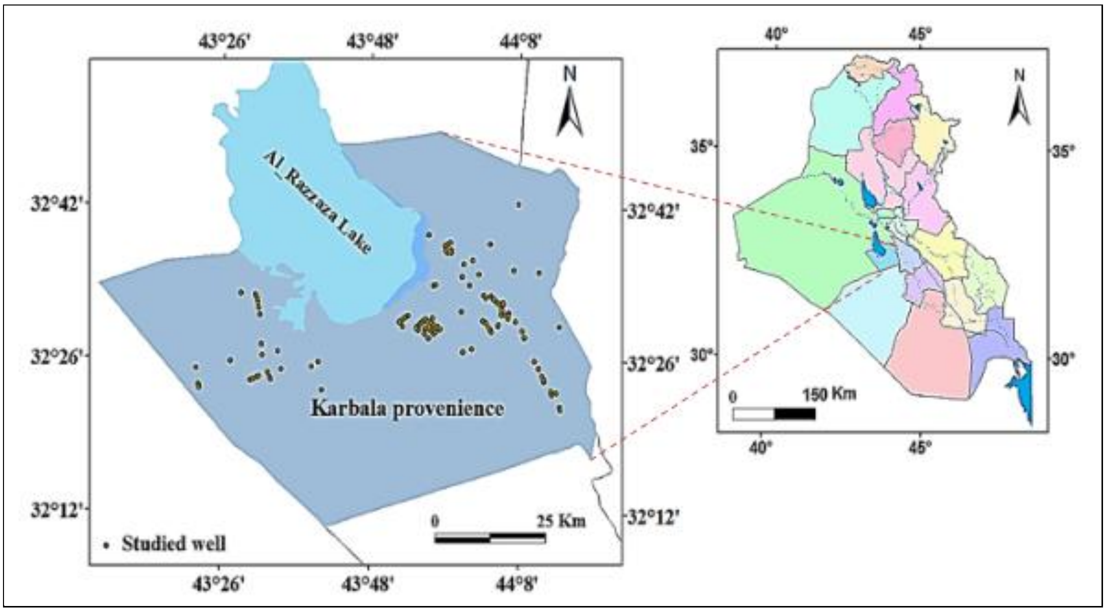


**Fig.1: Location map of the study area**

**Geology and hydrology of the study area**

The geological outcrops in the studied area represent the Dammam, Euphratees, Nfayl, Fatha, Injana, Zahar and Dibdiba Formation as well as the Quaternary deposits which covered 80% of the studied area. After studying existing literatures like [10], [11] and [12] , geological units were identified to prepare a thematic geological map of the region using Arc GIS 9.3 as displayed in Fig. (2).

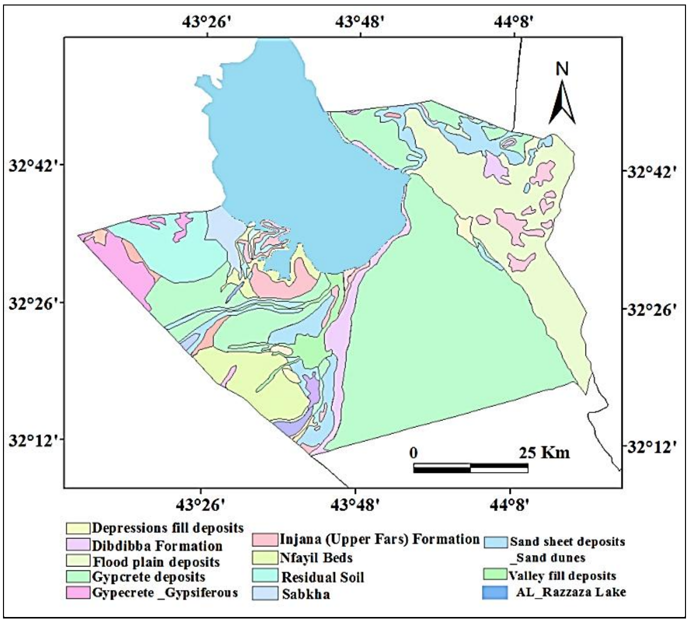


**Fig.2: Geological map of the study area**

Table 1 describes all geological formation in the area of study which is considered as a part of two structure zones. Salman Zone belongs to stable shelf and Mesopotamina zone of the unstable shelf [12]. From a topographic point of view the area can be divided into three regions; Mesopotamian plain, Desert plain, Bahr Al-Najaf and Raazaza depression.

Dammam and Umm Er Rathuma Formation are conceders as the main groundwater aquifers in the west of the studied area. Injana Formation represents the main aquifer within the terregenous deposits of

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the desert plain. Dammam and umm Er Rdhuma Formations represent the first and second aquifers within the carbonate rocks respectively. Quaternary deposits of the Mesopotamian plain represent the main aquifer at the east of studied area. The extensions of the Formation of Dammam and its stratigraphical position with other formations along the studied area are illustrated in Fig. 3. The depth of the groundwater varies from one location to another and generally deepens towards the central part of the studied area as shown in Fig. 4. The general direction of the groundwater flow is from west to east and from southwest to northeast at the western parts of the area , while the groundwater flow is from northwest toward southeast at the Mesopotamian plain with local diversions [6]. The most perennial hydrogeological feature in the studied area is the lake of Al-Razzaza.

**Table 1: Geological Formations in the studied area**

| Era | Period | | Age | Formation | Description |
|---|---|---|---|---|---|
| Cenozoic | Quaternary | | Pliocene – Pleistocene | Dibdibba | Sandstone, which is generally white, pink and light grey, will sorted, fine-coarse grained small pebbles are often reported. Sandstones contain mud balls, occasionally cross bedded. Other rock types are silty clay stone-clayey siltstone. |
| | | Neogene | Late Miocene | Injana (upper fares) | Generally, the formation consists of red, partly greenish silty, sandy calcareous claystone and lenticls of grey, brownish, greenish and yellowish sandstone. Thin beds (0.30 m.) of marly and chalky limestone are occasionally present in the sequence |
| | | | Middle Miocene | Fatha (Lower Fars) | Generally consist of green, partly reddish in places sandy, dolomitic and gypseous marl with interbedded calcareous, partly sandy claystone and fossiliferous limestone |
| | | | Middle. Miocene | Nfayil | Lenticular sequence of reddish sandy calcareous claystone and brownish coarse grained sandstone, with limestone intercalations (0.2-2.0 m.) |
| | | | Early. Miocene | Euphrates | Basal breccia, limestone and marl. sub rounded, re-crystallized and dolomitized a nummulitic limestone, fragments ranging in size from 1 cm. - 20 cm. cemented by limy material |
| | | Paleogene | Eocene | Dammam | Recrystallized anummulitic limestone, grey, creamy, yellowish and white in color, cavernous and Karstified |
| | | | Upper Paleocene | Umm Er Radhuma | Phosphates Limestone/ Dolostone, Dolomite |
| Mesozoic | Cretaceous | | Cretaceous | Tayarat | Dolomitic limestone, silty clay sandstone |

**Methodology**

A hundred and twenty two collected groundwater samples distributed along the area of study were chemically analyzed for elements include TDS, EC, pH, $Ca^{+2}$, $Na^{+}$, $Mg^{+2}$, $Cl^{-}$, $K^{+}$, $HCO_3^{-}$ and $SO_4^{-2}$ using the methods shown in the Table 2. Five parameters were selected in this study to calculate IWQI model. These parameters are: EC, $Na^{+}$, $Cl^{-}$, $HCO_3^{-}$ and SAR. Four of these parameters have been measured in the laboratory and (SAR) was calculated as the ratio of sodium absorption using the following equation

$$SAR = Na^{+} / \sqrt{(Ca^{2+} + Mg^{2+})/2} \quad ... (1)$$

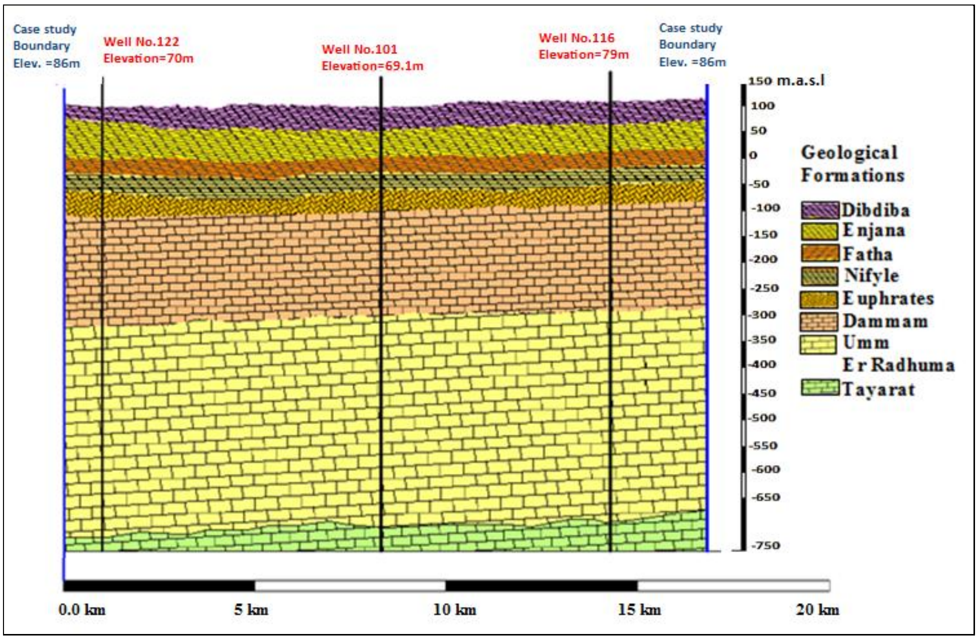


**Fig.3.The Stratigraphic correlation between the wells in the study area developed from [10] and [11]**

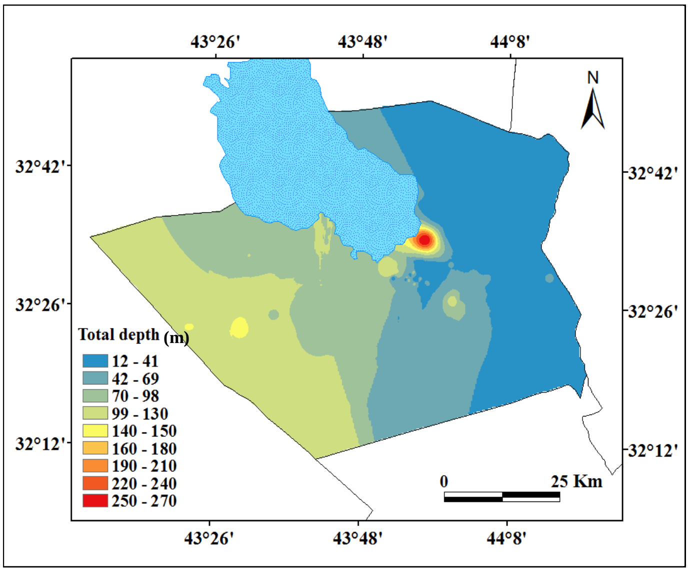


**Fig.4. Total depth to groundwater map of the study area**

All of those criteria were transferred to the GIS platform to create the database of water quality for the studied area and used to calculate the IWQI model.

**Table 2: Methods used to analyze water samples in the study area**

| Serial No | Parameters | Methods |
|---|---|---|
| 1 | pH, TDS and conductivity | Electrolytic |
| 2 | $Na^+$ and $K^+$ | Flame photometer |
| 3 | $Ca^{2+}$, $Mg^{2+}$, | EDTA titration |
| 4 | $HCO^{3-}$, | $H_2SO_4$ titration |
| 5 | $Cl^-$ | $AgNO_3$ titration |
| 6 | $SO_4^{2-}$ | Spectrophotometers |

**IWQI model calculation**

The calculation of the water quality index developed by [3] includes three phases:

1- Identifying the most suitable parameters for irrigation use, that is important to create the model were approved

2- Define values of accumulation weights ($w_i$) suggested by [3] based on its relative significance to irrigation water quality. Its normalized values and their total is equal one as presented in Table 3.

**Table 3: Weights for the IWQI parameters according to [3]**

| Parameter | Weight (wi) |
|---|---|
| EC | 0.211 |
| $Na^{+2}$ | 0.204 |
| $HCO_3^-$ | 0.202 |
| $Cl^-$ | 0.194 |
| SAR | 0.189 |
| Total | 1.0 |

3- **Qi** value was estimate based on different parameter recommended by [13] which is presented in Table 4. It represents non dimensional number where the higher value indicates the better water quality and vice versa. **Qi** value was calculated using the following equation:

$$Q_i = q_{imax} - \{[(x_{ij} - x_{inf}) * q_{iamp}]/x_{amp}\} \ldots(2)$$

Where, $q_{imax}$ is a maximal value of qi for the class, $x_{ij}$ is observed value of chemical parameter, $x_{inf}$ is minimal limit of the class to each parameter belongs; $q_{iamp}$ is class amplitude; and $x_{amp}$ is upper limit of the last class of each parameter.

**Table 4. Limiting values of (qi) calculations [13]**

| $HCO_3^{-1}$ | $Cl^-$ | $Na^+$ | SAR | EC (µS/cm) | $q_i$ |
|---|---|---|---|---|---|
| | (meq/l) | | $(meq/l)^{1/2}$ | | |
| $1 \le HCO_3 < 1.5$ | $1 \le Cl < 4$ | $2 \le Na < 3$ | $2 \le SAR < 3$ | $200 \le EC < 750$ | 85-100 |
| $1.5 \le HCO_3 < 4.5$ | $4 \le Cl < 7$ | $3 \le Na < 6$ | $3 \le SAR < 6$ | $750 \le EC < 1500$ | 60-85 |
| $4.5 \le HCO_3 < 8.5$ | $7 \le Cl < 10$ | $6 \le Na < 9$ | $6 \le SAR < 12$ | $1500 \le EC < 3000$ | 35-60 |
| $HCO_3 < 1$ or $HCO_3 \ge 8.5$ | $1 < Cl \ge 10$ | $Na < 2$ or $Na \ge 9$ | $2 \le SAR \ge 12$ | $EC < 200$ or $EC \ge 3000$ | 0-35 |

4- Irrigation water quality index has been calculated according to the following equation:

$$IWQI = \sum_{i=1}^{n} Qi * wi \ldots(3)$$

Where IWQI is none dimensional irrigation water quality index from 0 to 100; ***Qi*** is the quality measurement of the parameter, **($i_{th}$)** a number from (0 to 100) is a function of its concentration; and ***wi*** is the normalized weight of the **$i_{th}$** parameter.

Based on the proposed groundwater quality index which has sated by the existing groundwater quality index the values of IWQI for suitability of irrigation water class were divided into five dimensionless parameter classes ranging from (0 to 100) as shown in Table (5). Classes were defined depending on salinity hazard problems, soil water infiltration reduction and toxicity to plants suggested by [14] and [9].

**Table 5: Water Quality Index Characteristics [3]**

| Recommendation: Plant | Recommendation: Soil | Water use restrictions | IWQI |
|---|---|---|---|
| No toxicity risk for most plants | May be used for the majority of soils with low probability of causing salinity and sodicity problems, being recommended leaching within irrigation practices, except for in soils with extremely low permeability" | No restriction (NR) | 85-100 |
| Avoid salt sensitive plants | Recommended for use in irrigated soils with light texture or moderate permeability, being recommended salt leaching. Soil sodicity in heavy texture soils may occur, being recommended to avoid its use in soils with high clay | Low restriction (LR) | 70- 85 |
| Plants with moderate tolerance to salts may be grown | May be used in soils with moderate to high permeability values, being suggested moderate leaching of salts | Moderate restriction (MR) | 55- 70 |
| Should be used for irrigation of plants with moderate to high tolerance to salts with special salinity control practices, except water with low Na, Cl and $HCO_3$ values | May be used in soils with high permeability without compact layers. High frequency irrigation schedule should be adopted for water with EC above 2000 µS $cm^{-1}$ and SAR above 7.0 | High restriction (HR) | 40 -55 |
| Only plants with high salt tolerance, except for waters with extremely low values of Na, Cl and $HCO_3$ | Should be avoided its use for irrigation under normal conditions. In special cases, may be used occasionally. Water with low salt levels and high SAR require gypsum application. In high saline content water soils must have high permeability, and excess water should be applied to avoid salt accumulation | Severe restriction (SR) | 0-40 |

## Result and discussion

The type and quantity of salt governs the suitability of water usage for irrigation purpose. In general; there are four major sets of constraints related to irrigation water quality. Those sets are: (1) Salinity hazard, (2) Sodium hazard, (3) Diverse effects and (4) Toxicity of Specific ions, like $Cl^-$, $Na^+$, and trace elements."

### Salinity hazard

Electrical conductivity (EC) is a good measurement of salinity hazard to crop as it reflects the total dissolved salt in groundwater due to the function of the ionic solutes concentrations. The usual range of EC in irrigation water as mentioned by [15] is between 0-3000 (µS/cm). Electrical Conductivity of collected water samples from the studied area has been measured and spatial distribution map was prepared as displayed in Fig. 5. Generally it could be concluded that all sampling points were found unsuitable with respect to EC for irrigation purposes and it shows a large variation decreasing with the aquifer depth and increasing with groundwater flow direction. The large variation in EC is mostly attributed to water table depth and anthropogenic activities dominant in this area. The primary effect of high EC reduces the osmotic activity of plants and thus interferes with the absorption of water and nutrients from the soil. EC is measured by the passage of an electrical stream through a water sample and records the impedance in µ mhos/cm or dS/m [16].

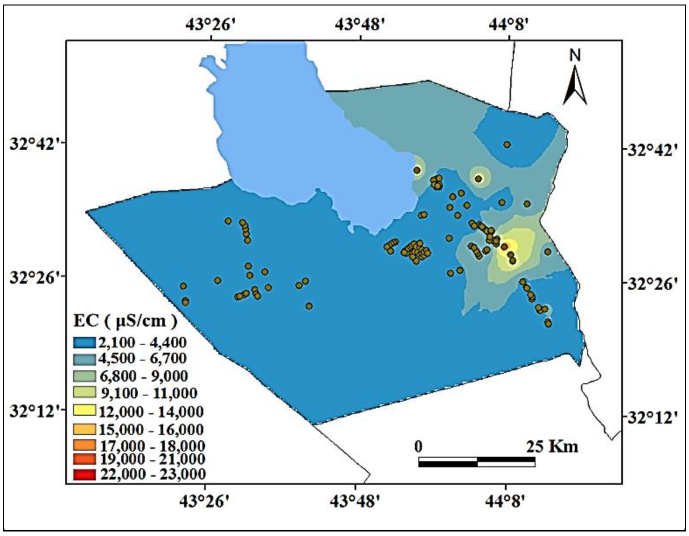


**Fig.5. EC Spatial distribution map of the study area**

**Sodium percentage (% Na)**

Sodium ions greatly effect on the soil permeability infiltration process, when sodium is highly concentrated wherever the soil becomes solid and compact when dry. This will effect on the structure of soil and leads to reduce rates of water and air leakage to the soil [17] and [18]. The presence of sodium ion in an exchangeable form in the soil, replaces the Calcium and Magnesium, this process causes the spreading of soil elements and thus the breakdown of their aggregates. The minimum calculated percentage of sodium present in the studied water sample is 4% and that increases to the northeast part of the studied area to reach 98%. Spatial distribution map for the Na% was prepared and displayed in Fig. 6.

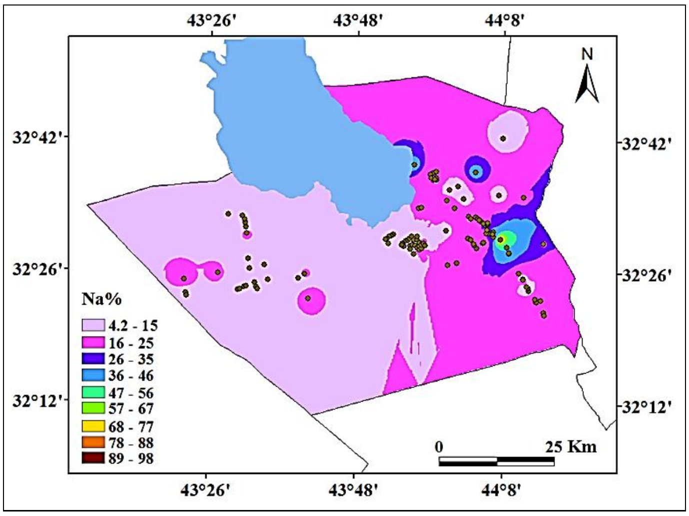


**Fig. 6: Na% spatial distribution map of the study area**

**Alkalinity hazard**

The sodium / alkaline hazard of irrigation water are determined with absolute and relative concentration of cations. This hazard is expressed as the ratio of sodium adsorption (SAR). The calculated values of SAR which were ranging from 1.6 to 16 have been transferred to GIS environment to create the spatial distribution of SAR map as displayed in Fig.7. According to [19], groundwater will not be suitable for irrigation if the value of the SAR is more than 18. Accordingly all studied samples are suitable for irrigation purposes. SAR values were found to be increasing from the SW to NE following the general movement of the groundwater flow direction.

**Toxicity and Miscellaneous effects**

Chloride ion is usually not included in modern water classifications because it does not affect the physical properties of soil, although it is an influential factor in some regional water classifications. While chloride ion is necessary for the plant at low concentrations, it could cause toxicity to sensitive crops at high concentrations. Spatial distribution map of chloride shows that the lowest concentration of chloride ion is four (4) at the southwestern part of the study area and increase towards the north-east to reach a value of 100 (meq/l) (Fig.8). Accordingly 15% of water samples are moderately tolerant plants and 85 % can cause severe problems. The pH and bicarbonate parameters are important factors, they were found to be within the range of the miscellaneous effects on sensitive crops. It should be carefully evaluated in irrigation water.

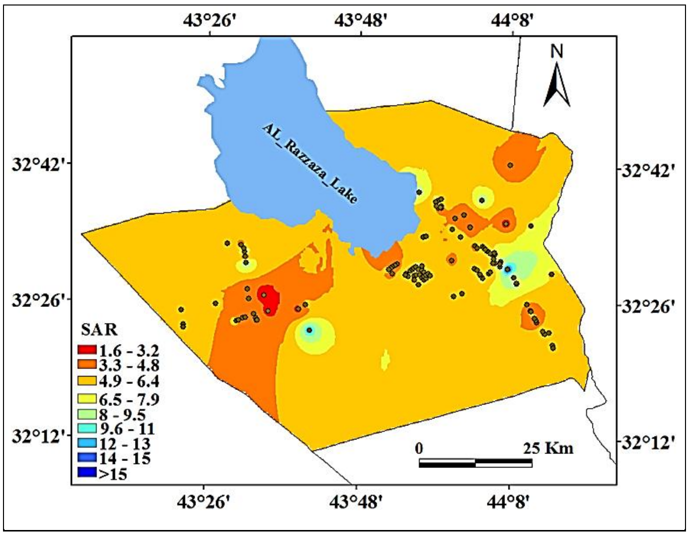


**Fig.7. (SAR) Spatial distribution map of the study area**

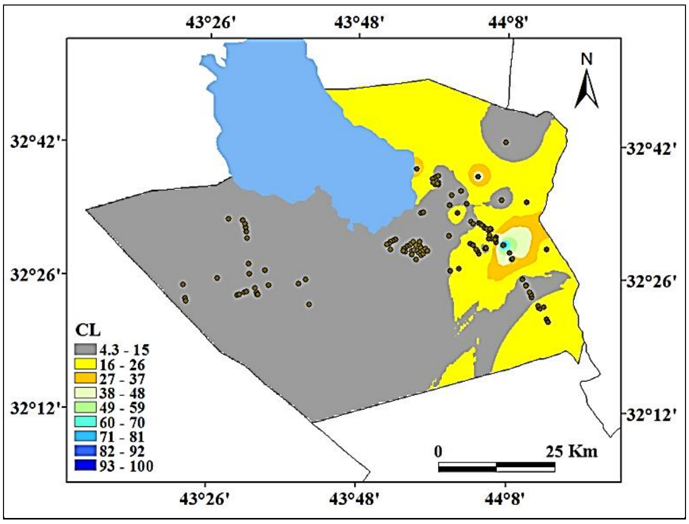


**Fig.8. $Cl^-$ spatial distribution map of the study area**

According to [15] the pH values range from 6.5 to 8.4 in the irrigation groundwater. Hence all studied water samples were within this range as displayed in Fig. 9. The bicarbonate ions are responsible for charging pH values up to more than 8.5 in the groundwater and therefore it could be considered the main component of alkalinity in groundwater [4].

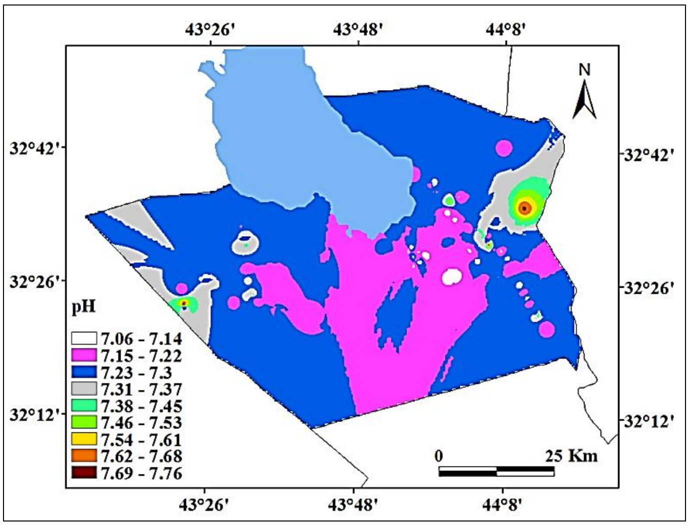


**Fig.9: pH spatial distribution map of the study area**

High carbonate concentrations make sodium ($Na^+$) ions predominant and form insoluble minerals in the solution [20]. Consequently, it is indirectly responsible for high concentrations of sodium and the hazards on irrigated crops and soil [1]. According to Ayers, (1985) [15] less than 90 mg/l is the perfect bicarbonate concentration for irrigation proposes. Thus only 5% of the studied sample less than 90 mg/l situated in the northwest and gradually increasing towards the north east of the study area as shown in Fig.10.

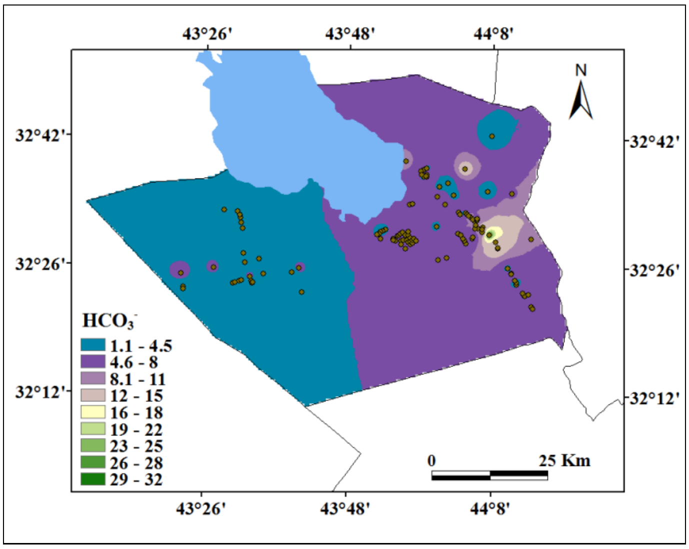


**Fig.10. $HCO_3^-$ spatial distribution map of the study area**

**Irrigation water quality index (IWQI) map**

The current study has been taken up with an objective to generate IWQI map using GIS technique to identify places with the best water quality for irrigation propose. To achieve this objective, five different sets of parameters were used that may have hazards and negative impacts on soil quality and productivity of yield. Grid datasets are created for each parameter using GIS technique within the domain of interest using inverse distance weight interpolation technique. Spatial distribution map of EC, SAR, $Na^+$, $Cl^-$ and $HCO_3^-$ have been integrated using ArcGIS Spatial Analyst extension according to Eq. (3). This integration gives the IWQ index map as a result of geostatistical analysis (Fig.11).

According to the IWQI map the groundwater suitability for irrigation in the study area divided into three water use restrictions classification namely, moderate restriction (MR); high restriction (HR) and severe restriction (SR). Towards the northeast 49% of groundwater becomes highly restricted covering an area 3,642km$^2$. This type of water may be used in soils with high permeability without compact layers. Forty three percent (43%) of the studied samples fall in **Sever Restriction (SR) categories** and should be avoided. This type of groundwater is not used for irrigation under normal conditions, but sometimes it could be used if the soil permeability is high and excess water is applied to avoid the accumulation of salt. Eight (8%) percent of the water sample falls in

**Moderate category (MR)**, which can be used in soil with medium values to high permeability, requiring moderate leaching of salts .

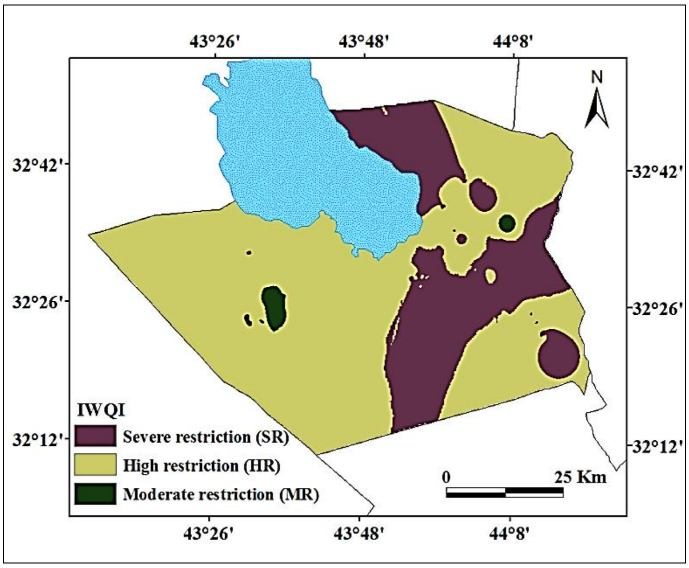


**Fig.11. Irrigation water quality index map of the study area**

## Conclusion

The current study has shown that GIS technique is a valuable tool for understanding the state of the groundwater quality in the study area and the availability of data will help specialists to determine where water is suitable for irrigation. Based on the results of the IWQI map, which was evaluating using GIS technique in the present study, the groundwater is not suitable for irrigation except for a small part that could be used under special conditions including medium values to high permeability soil, requiring moderate leaching of salts.

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# تطبيق تقنية نظم المعلومات الجغرافية لتقييم نوعية المياه الجوفية لأغراض الري

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*الكلية التقنية الهندسية ، الجامعة التقنية الوسطى*

**الملخص**

تم تطبيق تقنية نظم المعلومات الجغرافية في الدراسة الحالية لإنتاج خريطة لمؤشر نوعية مياه الري لمدينة كربلاء في العراق. ولهذا الغرض تم جمع مئة واثنان وعشرون عينة من المياه لمواقع متعدده في منطقة الدراسة وتم تحليلها لعناصر مختلفة تؤثر على نوعية مياه الري. على وجه التحديد، تم استخدام خمس محددات كيميائية هي التوصيلية الكهربائية (EC) وايون الكلور ($Cl^-$) والبكاربونات ($HCO3^-$) واالنسبة المؤية للصوديوم (Na%) ونسبة امتزاز الصوديوم (SAR) لإنشاء قاعدة بيانات لنوعية المياه في منطقة الدراسة والتي تم نقلها إلى بيئة نظم المعلومات الجغرافية (GIS) لغرض إنتاج خريطة توزيع مكاني لكل محدده من هذه المحدات باستخدام تقنية الاستكمال العكسي (Reverse Interpolation Technique) (IDW). وقد تم استخدام نتائج هذه المحددات ايضا لحساب قيم مؤشر نوعية مياه الري وإنتاج خريطة الفهرس (Index map) لنوعية جودة مياه الري باستخدام تقنيات نظم المعلومات الجغرافية وتبين من خلالها إن المياه الجوفية في المنطقة المدروسة غير صالحة للري باستثناء جزء صغير يمثل 8٪ من المساحة الكلية لمنطقة الدراسة والتي يمكن استخدامها مع الترب ذات النفاذية العالية والتي لها القدرة على تحمل نسبة عالية من الاملاح.

**الكلمات الدالة:** نظم المعلومات الجغرافية، مؤشر نوعية مياه الري، كربلاء، العراق.