

Assessment of Groundwater Quality in UMM ER Radhuma Aquifer (Iraqi Western Desert) by Integration Between Irrigation Water Quality Index and GIS

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Abstract

As groundwater is a vital source of water for domestic and agricultural activities in Iraqi Western Desert area due to lack of surface water resources, groundwater quality and its suitability for agricultural usage was evaluated. The aim of this study is to develop decision support tools for identifying the optimal locations of groundwater in terms of quality to meet the future demands in the western desert area. In order to assessment the groundwater quality for irrigation purposes in a way of high accuracy, the irrigation water quality index (IWQI) will be considered and developed (integrated with GIS) in this study to classify groundwater of the Umm Er Radhuma unconfined aquifer within Iraqi western desert area. For this purpose, 30 wells distribution within study area were chosen to take water samples during two periods (wet and dry season 2010) and analyzed for pH, electrical conductivity, total dissolved solids and major ions. Results suggest that, the use of GIS and water quality index (WQI) methods could provide a very useful and efficient tool to water resource management. The results analysis of (IWQI) maps confirms that: over 80% of the groundwater in study area falls within the "Severe restriction (SR)" and "High restriction (HR)" categories in dry period. This percentage reduced to 60% in wet period due to the dilution of water from rainfall. So, the groundwater from the south-eastern of the Umm Er Radhuma unconfined aquifer should be used only with the soil having high permeability with some constraints imposed on types of plant for specified tolerance of salts.

KEYWORDS: Irrigation Water Quality Index, GIS, Umm Er Radhuma Aquifer, Iraqi Western Desert

الخلاصة

تعتبر المياه الجوفية في منطقة الصحراء الغربية العراقية مصدرا مهما للاستخدامات العامة والزراعة بسبب عدم توفر المياه السطحية فيها. الهدف الرئيسي من هذه الدراسة هو تطوير أدوات دعم القرار لتحديد المواقع المثلى للمياه الجوفية من حيث نوعية المياه الصالحة للري في المنطقة وذلك لتلبية الطلب المتوقع في المستقبل على هذه المياه. ومن أجل تقييم نوعية المياه الجوفية لهذه المنطقة لأغراض الري بدقة عالية، فقد تم في هذا البحث استخدام الموديل الرياضي لمؤشر نوعية مياه الري (IWQI) للمنطقة بعد دمجها مع برنامج نظم المعلومات الجغرافية (GIS) وذلك لتصنيف المياه الجوفية لحشرج ام أرضمة الغير محصور في المنطقة. تم اختيار ٣٠ بئرا موزعة داخل منطقة الدراسة لأخذ نماذج من المياه الجوفية خلال فترتين (موسم الشتاء وموسم الصيف للعام ٢٠١٠) وتحليل هذه العينات من حيث الرقم الهيدروجيني و التوصيلية الكهربائية و المواد الصلبة الذائبة والأيونات الرئيسية. اظهرت النتائج إلى أن طريقة استخدام مؤشر جودة المياه (WQI) مع GIS يمكن أن توفر أداة مفيدة جدا وفعالة لإدارة الموارد المائية. كما بين تحليل نتائج خرائط (IWQI) على أن: أكثر من ٨٠٪ من المياه الجوفية في منطقة الدراسة يقع ضمن فئة التقييد الشديد (SR) و التقييد العالي (HR) لاستخدامات الري في فترة الجفاف (الصيف)، انخفضت هذه النسبة إلى ٦٠٪ في الفترة الرطبة (الشتاء) بسبب التخفيف الناتج عن مياه الأمطار. وعليه، فإن المياه الجوفية الواقعة في الجنوب الشرقي من حشرج ام أرضمة يجب أن تستخدم فقط مع التربة ذات النفاذية العالية و النباتات التي لها قدرة جيدة على تحمل نسبة الأملاح.

1. Introduction

The quality of groundwater is of nearly equal importance to quantity. The resource cannot be optimally used and sustained unless the quality of groundwater is assessed. The required quality of ground water supply depends upon its purpose (Todd, 2007).

The irrigation water quality and the associated hazards to soil characteristics and crop yield is often a complex phenomenon that involves the combined effect of many

parameters. A water quality index provides a single number that expresses overall water quality at a certain location and time based on several water quality parameters. The objective of an index is to turn complex water quality data into information that is understandable and useable by the public. A single number cannot tell the whole story of water quality; there are many other water quality parameters that are not included in the index. However, a water quality index based on some very important parameters can provide a simple indicator of water quality (Yogendra and Puttaiah, 2008).

Although Water Quality Index (WQI) is usually orientated to qualify urban water supply, it has been widely used by environmental planning decision makers. The quality of the irrigation water has to be evaluated to avoid or, at least, to minimize impacts on agriculture (Mohammed, 2011).

Groundwater quality analysis and geographic information system (GIS)-based mapping are important components of a groundwater planning strategy. Analysis based on hydrochemical studies can reveal potential contaminated zones and indicate suitability of water for drinking, irrigation, or other purposes. GIS can be used to identify areas affected by groundwater pollution and to obtain other reliable information about current groundwater quality scenarios that may be essential for the effective and efficient implementation of water management programs.

Researchers at the United States Salinity Laboratory (USSL) (1954) and Wilcox (1955) established the standards for irrigation water. Also in 1962, the U.S. Public Health Service (1962) established standards for the drinking water [quoted by (Alavi, 2010)]. The need for such readily understood evaluation tool was ultimately realized, and several researchers (e.g. Brown et al., 1970; Prati et al., 1971; Landwehr, 1979; Bhargava, 1985; Dinius, 1987 and Smith, 1990) have developed their own rating schemes.

So far, many researches and projects have been conducted to measure water quality index. Simsek & Gunduz (2007), Jerome¹ and Pius (2010) and Rokbani et al. (2011) used irrigation water quality index (IWQI) as a management tool for groundwater quality. Meireles et al., (2010) classify water quality in the Acarau Basin, in the North of the state of Ceara, Brazil for irrigation use.

In spite of the large number of studies regarding general water quality index techniques, no complete assessment tool has been found in the literature that incorporates all the crucial aspects parameters of irrigational water quality analysis. Furthermore, it has also been realized that GIS-integration of irrigation water quality assessment has not been done to the extent that this study intends to perform. Thus, an Irrigation Water Quality (IWQ) index is developed in this study to provide an easy-to-use tool that could help analyze the overall quality of irrigation water. The technique also allows the decision maker perform a spatially distributed analysis from a broader perspective.

The main purposes of this study were to develop the IWQI which established by Meireles et al., (2010) through integrated it with GIS in order to identify places with the best water quality for irrigation by map irrigation water quality index (IWQI). Moreover, study the sensitivity of (IWQI) with two time periods (dry and wet seasons).

The integration of the geographic information system (GIS) platform to the assessment procedure not only allows the decision maker to create parameter maps for easy visual interpretation but also makes the overall analysis more sound, objective and simple.

2. Study area

The studied area is located between the Euphrates River and the Saudi Arabian borders, it forms about (60,068) km² of the Iraqi western desert covering the unconfined aquifer of Umm Er Radhuma geological formation inside Iraq, figure (1), which is often considered of a great importance in the Iraqi desert as well as in Saudi Arabia.

Umm Er Radhuma aquifer is considered as a major aquifer in the Iraqi western desert and a potential regional transboundary aquifer shared with Saudi Arabia and Kuwait. Its importance to Iraq is due to its vast extension and its location near the surface of the ground as well as to its groundwater quality which is considered relatively good compared to other aquifers in the western desert.

2.1 Hydrogeology of Umm Er Radhuma aquifer

Umm Er Radhuma formation is characterized by a wide extension in the western and southern deserts; furthermore its extension covers most parts of the northern desert excluding Rutba uplift. It is divided into two aquifer types: confined and unconfined. The confined aquifer (91,766 km²) is normally found in the eastern and the northeastern parts of the northern desert and most parts of the southern desert, while the unconfined aquifer (60,068 km²) found in the west of the northern desert and the west and southwestern parts of the southern desert near the Iraqi-Saudi Arabia borders [Figure (1)].

The boundary of the unconfined aquifer lies toward Rutba uplift. The formation in the same uplift is considered as a dry aquifer and its boundaries are changeable due to the recharge which may result from precipitation. It is located to the east of Rutba uplift since the outcrops of the formation which are exposed at the uplift itself do not form an aquifer. To the west of the uplift and towards the Jordanian borders, the formation has a limited exposure and is totally dry inside Iraq. Figure (1) shows the extents of both the unconfined and confined aquifers in Umm Er Radhuma formation where it could be noted that along the national borders at the southern desert the aquifer is usually unconfined.

The exposed surface of the formation and the extent of its unconfined aquifer represent all the recharge areas of the aquifer. Umm Er Radhuma unconfined aquifer changes to a confined one when flowing eastwards toward Euphrates River in areas that extends in the northern desert in Husaybah, through Ana and Heat reaching Bahr Al-Najaf. It constitutes, with Dammam aquifer which lies above it, an aquifer system with possible hydraulic connection between the two aquifers. The piezometric pressure is equal in the two aquifers in these regions when measured in wells penetrating them both.

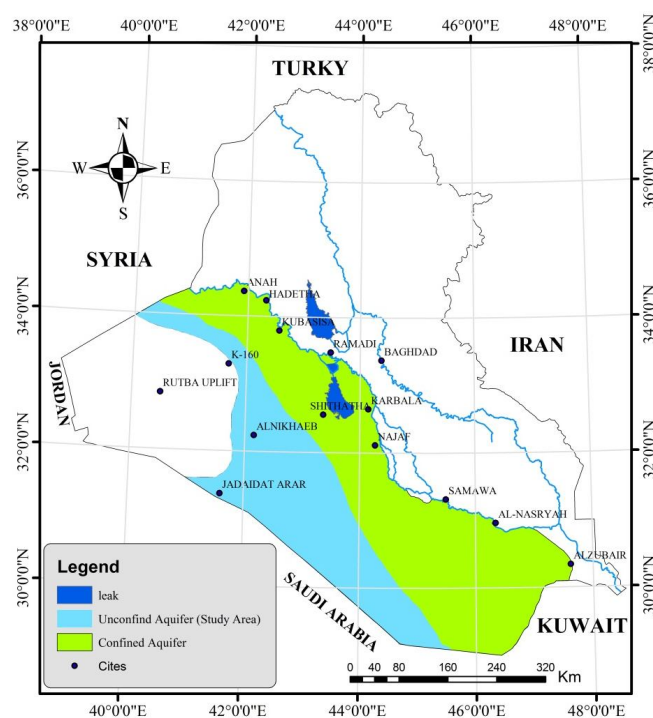


Figure (1): Extents of the two types of aquifers in Umm Er Radhuma formation

This connection is not observed between these two aquifers in the southern desert due to the presence of the impermeable evaporate and marl beds of Rus formation which separate the two aquifers from each other (Al Jawad, et al. 2001).

The saturated thickness of the unconfined aquifer ranges between (50) m in the west of the southern desert near the international borders to (213) m in the east where the unconfined aquifer becomes confined, (Al Jawad, et al.2001). Rainfall is considered as the most important source of groundwater recharge. In spite of the prevailing arid desert climate in the studied area, the low rainfall occurrences are described as heavy and intermittent leading to occasional flow events that may cause floods in valleys and depressions. Umm Er Radhuma Formation, is also, recharged by subsurface flow of the upcoming water of the aquifer in Saudi Arabia entering the basin from the south, the south- west and the west margins of the region through faults and subsurface channels.

The regional trend of groundwater movement in the Umm Er Radhuma unconfined aquifer is generally towards the east and the northeast. But, locally, the flow of groundwater takes different directions throughout the region depending on geological, topographic and structural features as show in Figure (2).Groundwater flow pattern in Umm Er Radhuma aquifer is affected mainly by the permeability and the fractured density of the rock units that contain groundwater and by the hydraulic gradient.

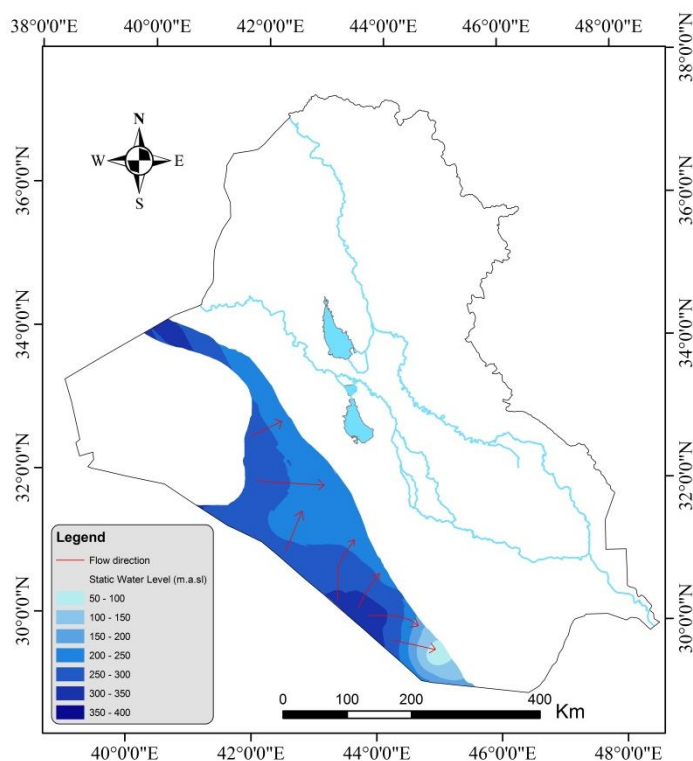


Figure (2): Groundwater movement of Umm Er Radhuma unconfined aquifer.

3. Material and Methodology

Samples were collected from groundwater wells [Figure (3)] representing dry and wet- periods to evaluate the seasonal variations in chemical composition (Al-Fatlawi, 2011). Techniques and methods followed for collection, preservation, analyses and interpretation of water samples are those given by standard methods (APHA ,1995).

In situ, measurements included electrical conductivity (EC), TDS, pH and temperature. Laboratory tests were carried out to find the ion concentrations of (Ca^{+2} , Mg^{+2} , Na^{+} , Cl^{-} , SO_4 and HCO_3^{-}) in (mg/l). Statistical measures for physical and chemical parameters, such as minimum, maximum, mean and standard deviation, are reported in Table (1) and Table (2) for wet and dry periods respectively.

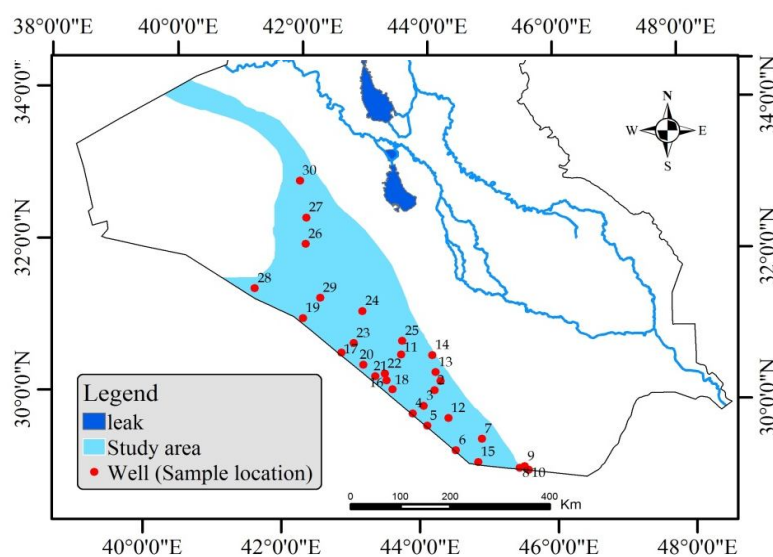


Figure (3): Locations of the water samples of the well in the study area.

Table (1): The results of water quality analysis for the aquifer in study area (wet season).

30 Samples	Parameter(wet season)								
	EC ($\mu\text{S}/\text{cm}$)	TDS (mg/l)	pH	Ca ⁺² (mg/l)	Mg ⁺² (mg/l)	Na ⁺ (mg/l)	Cl ⁻ (mg/l)	SO ₄ ⁻² (mg/l)	HCO ₃ ⁻
Minimum	1235	1050	6.9	1.7	0.99	3.83	2.12	1.35	0.23
Maximum	7280	5870	8.68	18.71	16.28	41.2	29.61	27.21	13.29
Mean	2783.7	2003	7.6	7.624	5.264	13.8	12.29	10.67	3.447
Std.Dev.	1329	952.4	0.5	4.153	3.44	7.73	5.509	6.357	2.632

Table (2): The results of water quality analysis for the aquifer in study area (dry season).

30 Samples	Parameter(dry season)								
	EC ($\mu\text{S}/\text{cm}$)	TDS (mg/l)	pH	Ca ⁺² (mg/l)	Mg ⁺² (mg/l)	Na ⁺ (mg/l)	Cl ⁻ (mg/l)	SO ₄ ⁻² (mg/l)	HCO ₃ ⁻
Minimum	1445	1090	7.08	1.9	1.15	5.3	3.3	2.29	0.4
Maximum	7790	6000	8.8	19.41	16.28	43.5	30.91	28.11	13.51
Mean	3058.2	2164	7.73	8.1	5.904	15.5	13.57	11.93	3.673
Std.Dev.	1376.	953.5	0.48	4.1	3.428	7.49	5.537	6.502	2.6487

3.1 The Suitability of Groundwater for Irrigation Purposes

These last years, the Irrigation Water Quality Index (IWQI) was very used to determine the suitability of the groundwater for irrigation purposes. Irrigation Water Quality Index (IWQI) is a very useful tool for communicating the information on the overall quality of water. The quality of irrigation water is highly variable depending upon both the type and the quantity of the salts dissolved in it. These salts originate from natural (i.e., weathering of rocks and soil) and anthropological (i.e., domestic and industrial discharges) sources and once introduced, they follow the flow path of the water. It is commonly accepted that the problems originating from irrigation water quality vary in type and severity as a function of numerous factors including the type of the soil and the crop, the climate of the area as well as the farmer who utilizes the water. Nevertheless, there is now a common understanding that these problems can be categorized into the following major groups: (a) salinity hazard, (b) infiltration and permeability problems, (c) Specific ion toxicity and (d) miscellaneous problems (Simsek and Gunduz, 2007).

Salinity Hazard

Salinity hazard occurs when salts start to accumulate in the crop root zone reducing the amount of water available to the roots. This reduced water availability sometimes reaches to such levels that the crop yield is adversely affected.

These salts often originate from dissolved minerals in the applied irrigation water or from a high saline water table. The reductions in crop yield occur when the salt content of the root zone reaches to the extent that the crop is no longer able to extract sufficient water from the salty soil. When this water stress is prolonged, plant slows its growth and drought-like symptoms start to develop (Ayers & Westcot, 1985). Unless the soil is leached with low salt content water, the salinization of the soil is an irreversible process that makes agricultural lands unusable.

Being the most influential water quality guideline on crop productivity, the extent of salinity hazard could be measured by the ability of water to conduct an electric current. Since conductance is a strong function of the total dissolved ionic solids, either an electrical conductivity (EC) measurement or a total dissolved solids (TDS)

analysis could be used in measuring the salinity of water. In general, the amount of water available to the crop gets lower when the electrical conductivity is higher. Under such circumstances, the soil appears to be wet but the crop experiences the so-called physiological drought. Since plants can only transpire 'pure' water, the usable portion of water by plants decreases dramatically as conductivity increases. Usually, waters with EC values of below 700 $\mu\text{S}/\text{cm}$ are considered to be good quality irrigation waters (Ayers & Westcot, 1999).

Permeability and Infiltration Hazard

Although the infiltration rate of water into soil is a function of many parameters including the quality of the irrigation water and the soil factors such as structure, compaction and the organic content, the permeability and infiltration hazard typically occurs when high sodium ions decrease the rate at which irrigation water enters the soils lower layers. The reduced infiltration rate starts to show negative impacts when water cannot infiltrate to the roots of the crop to the extent that the crop requires. Hence, these salts start to accumulate at the soil surface. When the crop is not able to extract the required amount of water from the soil, it is not possible to maintain an acceptable yield and the agricultural production is reduced (Simsek & Gunduz, 2007). The most common water quality factor that influence the normal rate of infiltration of water is the relative concentrations of sodium, magnesium and calcium ions in water that is also known as the sodium adsorption ratio (SAR). The SAR value of irrigation water quantifies the relative proportions of sodium (Na^+) to calcium (Ca^{+2}) and magnesium (Mg^{+2}) and is computed as (Ayers & Westcot, 1985):

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

Where:

SAR: Sodium Adsorption Ratio (meq/l)^{1/2}

Na^+ , Ca^{+2} , and Mg^{+2} : Concentration of Ions by milliequivalents per liter (meq/l) units.

Specific Ion Toxicity

Sodium

The detection of sodium toxicity is relatively difficult compared to the toxicity of other ions. Typical toxicity symptoms on the plant are leaf burn, scorch and dead tissue along the outside edges of leaves in contrast to symptoms of chloride toxicity which normally occur initially at the extreme leaf tip (Simsek and Gunduz, 2007).

Chloride

Chloride is another ion commonly found in irrigation waters. Its toxic effects are immediately seen as leaf burns or leaf tissue deaths.

Miscellaneous Effects

Bicarbonate

Alkalinity is a measure of the capacity of water to neutralize an added acid. Being the major component of alkalinity, carbonate and bicarbonate ions are generally responsible for high pH values (i.e., above 8.5) of water. Elevated levels of carbonates cause calcium and magnesium ions to form insoluble minerals leaving sodium as the dominant ion in solution (Simsek and Gunduz, 2007).

3.2 Irrigation Water Quality Index (IWQI) model:

IWQI model which was developed by (Meireles et al., 2010) was applied to the data, and programming it with GIS software. In the **First step**, identified the parameters were considered more relevant to the irrigation use. In the **Second step**, a definition of quality measurement values (q_i) and aggregation weights (w_i) was established. Values of (q_i) were estimated based on each parameter value, according to irrigation water quality parameters proposed by the University Of California Committee Of Consultants - UCCC and by the criteria established by Ayers and Westcot (1999) as shown in Table (3). Water quality parameters were represented by a non-dimensional number; the higher the value is the better water quality.

Table (3): Parameter limiting values for quality measurement (q_i) calculation (Ayers and Westcot, 1999).

HCO ₃ ⁻	Cl ⁻	Na ⁺	SAR (meq/l) ^{1/2}	EC (μS/cm)	q _i
meq/l					
1≤HCO ₃ <1.5	Cl<4	2≤Na<3	SAR<3	200≤EC<750	85-100
1.5≤HCO ₃ <4.5	4≤Cl<7	3≤Na<6	3≤SAR<6	750≤EC<1500	60-85
4.5≤HCO ₃ <8.5	7≤Cl<10	6≤Na<9	6≤SAR<12	1500≤EC<3000	35-60
HCO ₃ <1 or HCO ₃ ≥8.5	Cl≥10	Na<2 or Na≥9	SAR≥12	EC<200 or EC≥3000	0-35

Values of q_i were calculated using the equation (2), based on the tolerance limits shown in Table (3) and water quality results determined in laboratory:

$$q_i = q_{imax} - \left\{ \frac{[(x_{ij} - x_{inf}) \times q_{iamp}]}{x_{amp}} \right\} \quad (2)$$

Where q_{imax} is the maximum value of q_i for the class; x_{ij} is the observed value for the parameter; x_{inf} is the corresponding value to the lower limit of the class to which the parameter belongs; q_{iamp} is class amplitude; x_{amp} is class amplitude to which the parameter belongs.

In order to evaluate x_{amp} , of the last class of each parameter, the upper limit was considered to be the highest value determined in the physical-chemical and chemical analysis of the water samples. Each parameter weight used in the IWQI was obtained by (Meireles et al., 2010) as shown in Table (4). The w_i values were normalized such that their sum equals one. The irrigation water quality index (IWQI) was calculated as:

$$IWQI = \sum_{i=1}^n q_i w_i \quad (3)$$

IWQI is a dimensionless parameter ranging from 0 to 100; q_i is the quality of the i^{th} parameter, a number from 0 to 100, function of its concentration or measurement; w_i is the normalized weight of the i^{th} parameter, function of its relative importance to groundwater quality. Division in classes based on the proposed water quality index was based on existent water quality indexes, and classes were defined considering the risk of salinity problems, soil water infiltration reduction, as well as toxicity to plants as observed in the classifications presented by Bernardo (1995) and Holanda and Amorim (1997). After the total value of the index is computed, restrictions to water use classes were characterized as shown in Table (5).

Table (4): Weights for the IWQI parameters (Meireles et al., 2010).

Weight (w_i)	Parameter
0.211	EC
0.204	Na
0.202	HCO ₃
0.194	Cl
0.189	SAR
1.0	Total

Table (5): Water Quality Index Characteristics (Meireles et al., 2010).

Recommendation		Water use restrictions	IWQI
Plant	Soil		
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 $\mu\text{S cm}^{-1}$ 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

4. Results and Discussions

Once the water quality database given in Tables 1 and 2 is transferred into GIS platform, grid datasets are created for each parameter within the domain of interest using inverse distance interpolation technique. The spatial distributions of these quality parameters are assessed with particular reference to the individual hazard groups discussed in previous sections. Then parameter grids are transformed into index grids using a computer program established for this purpose. The individual parameter indices are then processed according to Equation (3) and five index maps are created for the corresponding hazard groups. Finally, these group maps are combined to form the final IWQ index map.

4.1 Assessment of individual hazard groups

4.1.1 Salinity hazard

The spatial distribution of electrical conductivity measured in samples collected from 30 wells is presented in Figures (4a) for wet season. It can be seen from the

figure that EC values are observed to cover a wide range from 1235 $\mu\text{S}/\text{cm}$ measured at well no.26 to 7280 $\mu\text{S}/\text{cm}$ measured at well no.10. As EC demonstrates the salinity hazard, one can conclude that the agricultural fields around ALNIKHAEB have the best quality irrigation water when salinity risks are considered. The (EC) values of the wet period are slightly lower than the dry period due to dilution process by rainfall as show in figure (5a).

4.1.2 Infiltration hazard

The SAR values increases spatially from the north-west to south-east following the general trend of the aquifer flow direction [Figures (4b and 5b)].

4.1.3 Specific Ion Toxicity

The sodium ion (Na^+) concentration of water samples ranged between (3.83ppm) to (41.2ppm) with mean (13.8 ppm) for wet season. Spatial distributions of sodium ion (Na^+) concentration in the studied area are shown in Figure (4c) for wet season and Figure (5c) for dry season. Chloride concentrations are presented as the other parameter defining the specific ion toxicity. The chemical analysis of water samples in wet season showed that the average chloride ion concentrations in the study area (12.29ppm) and the maximum and minimum values (29.61 ppm), (2.12 ppm) respectively (Table 1). Spatial distributions of chloride ion concentrations are shown in Figures (4d and 5d) for wet and dry seasons respectively in meq/l unit. For each figure is shown that the chloride ion concentrations relatively high values in all water sampling as compared to the value of good quality irrigation water (4 meq/l).

4.1.4 Miscellaneous effects

The bicarbonates ion (HCO_3^-) concentration of water samples ranged between (0.23ppm) to (13.29ppm) with mean (3.45ppm) in wet season (Table 1). In general, the bicarbonate concentrations values of below 90 mg/l (1.5 meq/l) are considered to be ideal for irrigation (Ayers & Westcot, 1985). Spatial distributions of bicarbonate ion concentrations are shown in Figure (4e) in meq/l unit for wet season and Figure (5e) for dry season.

The bicarbonate ion concentration is relatively low compared to chloride and sulfate ion concentrations (range: 0.23-13.29ppm for wet season and 0.4 -13.51ppm for dry season) [Tables (1 and 2) and Figure (4e) Figure (5e)].

The predominant cation trend in Umm Er Radhuma aquifer is $\text{Na}^+ > \text{Ca}^{+2} > \text{Mg}^{+2}$. Sodium is the dominant cation in Umm Er Radhuma aquifer. Its concentration ranges between 7.73 and 7.49ppm for wet and dry seasons respectively. The abundance of the major anions in Umm Er Radhuma unconfined aquifer is in the following order: $\text{SO}_4 > \text{Cl} > \text{HCO}_3$. The Umm Er Radhuma unconfined aquifer is characterized by a high sulfate ion content-which is the dominant anion.

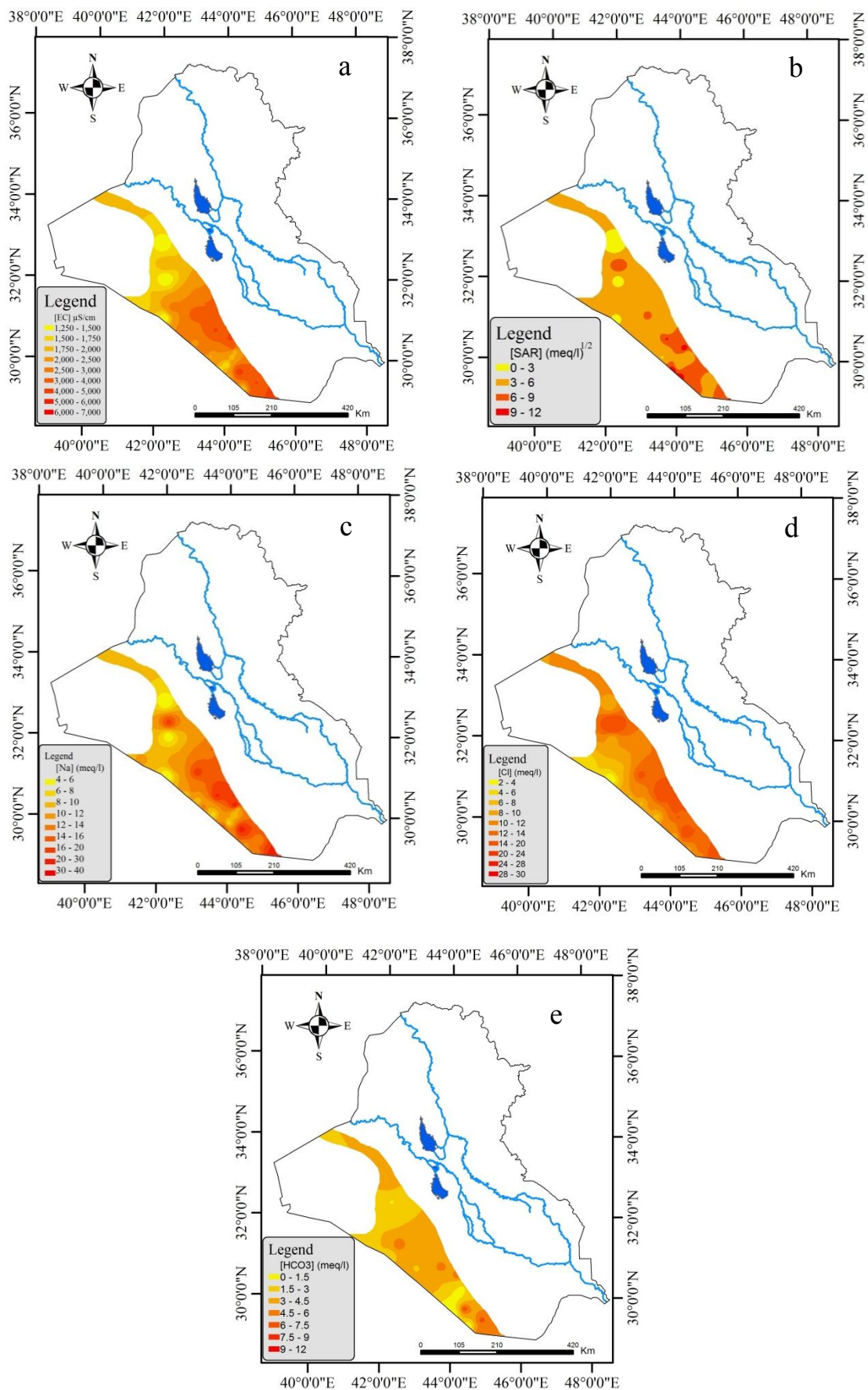


Figure (4): Spatial Distribution of a) EC, b)SAR, c)Na, d)Cl, e) HCO_3 Concentrations at wet season in the Study Area

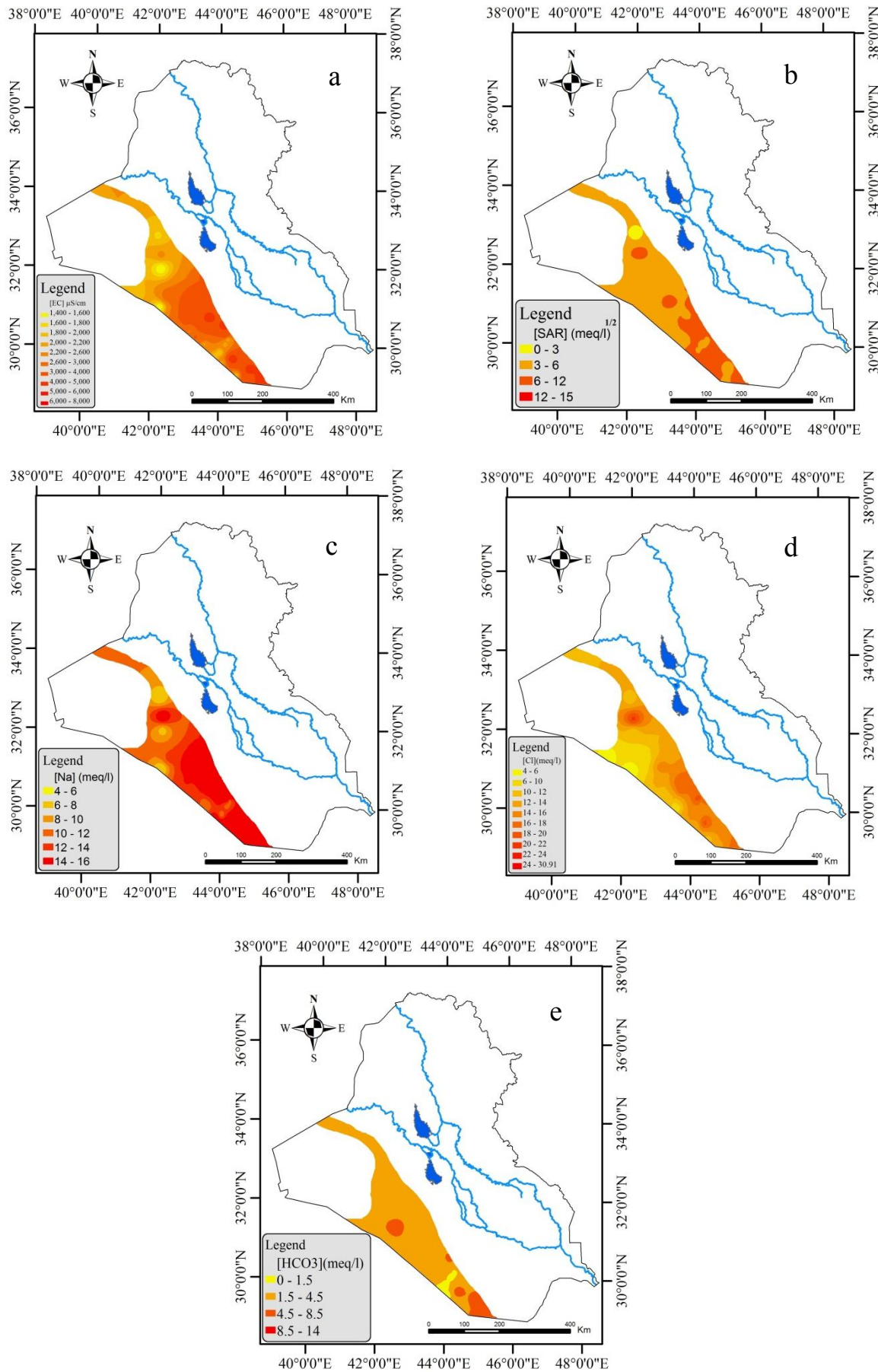


Figure (5): Spatial Distribution of a) EC, b) SAR, c) Na, d) Cl, e) HCO₃ Concentrations at dry season in the Study Area

4.2 Irrigation Water Quality Index (IWQI) maps:

Figure (6) shows the steps to found the final irrigation water quality index (IWQI) map that was produced by overlapping of the thematic maps (EC, SAR, Na, Cl and HCO_3) as a result of geostatistical analysis. The spatial integration for groundwater quality mapping was carried out using ArcGIS Spatial Analyst extension according to Eq. (3). This integration gives the IWQ index map shown in Figure (7) and Figure (8) for wet and dry seasons respectively. These figures represent the spatial distribution of the IWQ index within the domain of interest and could be considered as a general suitability map for providing irrigation water from the aquifer. Since the map shows the spatial distribution of groundwater quality in the plain as index values, it is now much easier for a decision maker to assess the quality of groundwater for irrigation purposes and further locate the most suitable site for drilling wells to extract irrigation waters.

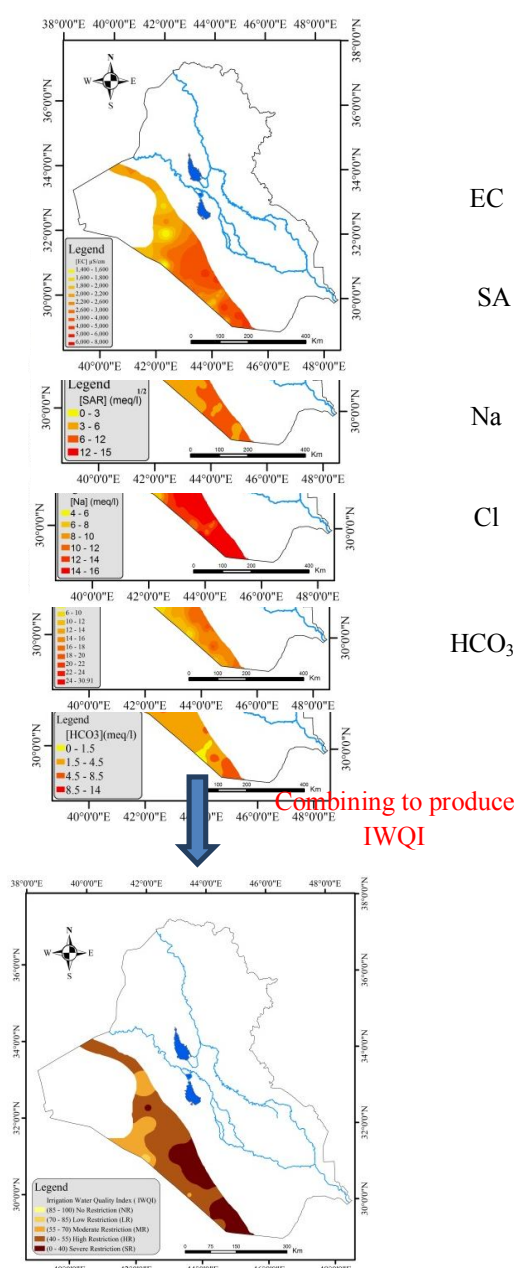


Figure (6): Steps for creating Irrigation Water Quality Index.

Figure (7) shows spatial distribution of IWQI in the wet season for study area and it is varying from severe restriction (SR) to low restriction (LR) according to verify it with Table (5). The area for (High restriction) water quality could be found on a large area at the southeast and at the center of the study area. These areas for (High restriction) water quality cover 46.8% (about 28136 km²) of total study area. The rest of the study area, which is about 13.7% (8215 km²), has water classified as (Severe restriction) quality levels, 38% (Moderate restriction) and only 1.5% has Low restriction (Table 6). In addition, The IWQI was decrease from west-north to south-east, because of increase the electrical conductivity, SAR, Sodium ion, Chloride ion in this direction as shown in Figure 4 (a, b, c and d) respectively. According to the recommendation in Table (5) these types of water (expected area of low restricted 1.5%) should be used only with the soil have high permeability. Fortunately; all the study area located in Iraqi Western desert which have very high permeability soil (sand). So, the groundwater could be used in irrigation with some constrains in type of plant with tolerance to salt as mentioned in table (5).

The spatial distribution map of the IWQI in dry season (Figure 8) shows that the south-west of the study area has very poor (severe restriction) groundwater quality; and in general, the groundwater quality decreases from the north-west to the south-east of the Umm Er Radhuma unconfined aquifer, under the effects of the hydraulic gradient.

IWQI decreases to the east as well as the south eastern part of the studied area due to the dissolving as a result to the movement of the water towards the discharge area. As shown from Figure (7) and Figure (8), the values of IWQI increases through the wet period, because the dilution of water from rainfall.

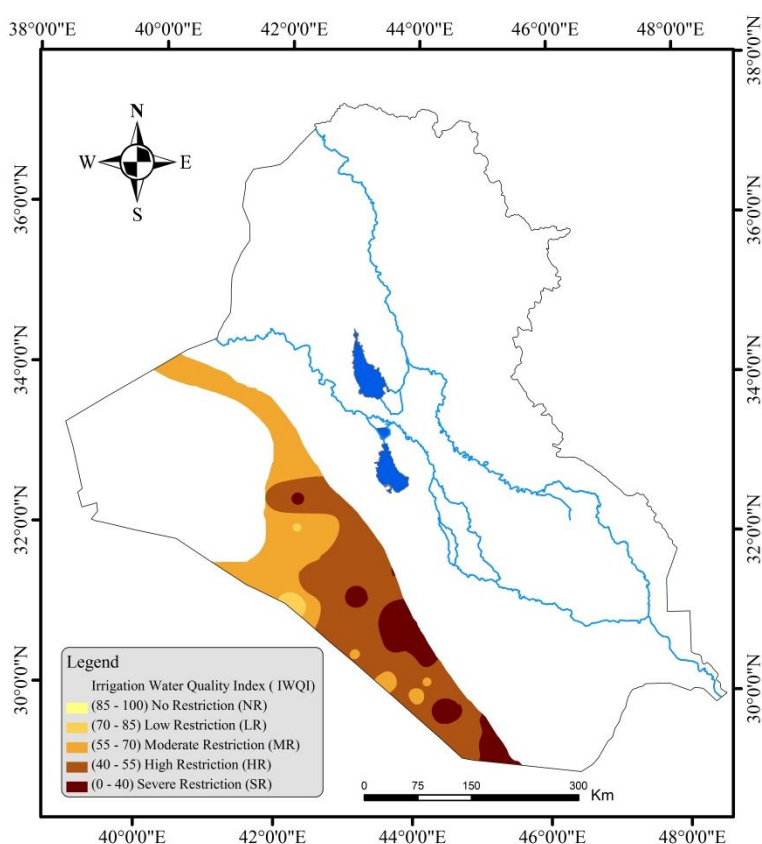


Figure (7): Irrigation Water Quality Index (IWQI) for the study area in wet season.

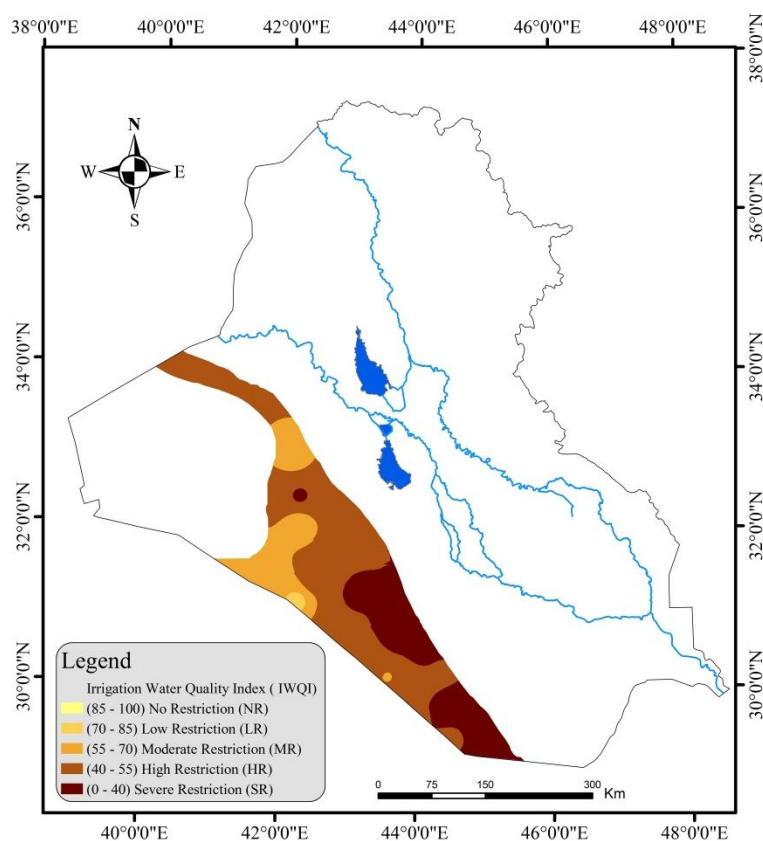


Figure (8): Irrigation Water Quality Index (IWQI) for the study area in dry season.

Table (6): Irrigation water quality index classes of the study area.

Wet season		Dry season		Water use restrictions	IWQI
Percent from total study area	Area (Km ²)	Percent from total study area	Area (Km ²)		
1.5%	859	0.7%	405	Low restriction (LW)	70-85
38%	22858	18.9%	11347	Moderate restriction (MR)	55-70
46.8%	28136	52.5%	31582	High restriction (HR)	40-55
13.7%	8215	27.9%	16734	Severe restriction (SR)	0-40
100%	60068	100%	60068	Total	

4.2 Conclusion

The primary objective of this study was to map and evaluate the groundwater quality in Umm Er Radhuma unconfined aquifer within Iraqi Western Desert area. Spatial distribution of groundwater quality parameters were carried out through GIS and irrigation water quality index techniques. The use of GIS and water quality index (WQI) methods could provide a very useful and an efficient tool to summarize and to report on the monitoring data to the decision makers in order to be able to understand the status of the groundwater quality; and to have the opportunity for better use in future as well.

Based on the results of the irrigation water quality index (IWQI) map, the best irrigation water quality in Umm Er Radhuma unconfined aquifer is found in the recharge zone at the western edge of the aquifer where it is recharged by Wadi Horan. In both dry and wet periods, the ground water IWQI type ranges between (LR - MR), decreasing with the flow direction toward the east and the southeast until it attains a type of (SR) in the discharge zone of the desert. When utilized for any purpose, the aquifer in the recharge zone must be well managed and protected from contamination. Also, the best possible investment areas for agriculture were found to the north and northern west of the study area.

For dry period, over 52% of the study area fall within the "High restriction" category, which is the dominant in the central and southeast parts of the study area. This percentage reduced to 46.8% in wet period due to the dilution of water from rainfall.

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