JJEES
Jordan Journal of Earth and Environmental Sciences

JJEES (2019) 10 (1): 15-20
ISSN 1995-6681

Groundwater Quality Assessment Using Irrigation Water Quality Index and GIS in Baghdad, Iraq

Mufid Al-Hadithi[1], Karima Hasan[2], Amer Algburi[3], Kamal Al-Paruany[4]

[1]Middle Technical University, Engineering Technical College, Baghdad, Iraq
[2]Middle Technical University, Institute of Technology, Baghdad, Iraq
[3]University of Anbar, College of Science, Iraq
[4]Ministry of Science and Technology, Iraq

Received 25 August, 2018; Accepted 17 January, 2019

Abstract

Twelve water samples were collected to evaluate groundwater quality in Baghdad city, Iraq using the irrigation water quality index (IWQI) method with the help of the Geographical Information System (GIS) technique. Five chemical parameters were used including Electrical Conductivity (EC), Cl^-, HCO_3^{-1}, Na % and Sodium Absorption Ratio (SAR) to create the database of water quality. These parameters have been inputted to the GIS platform to produce a spatial distribution map for each parameter using the inverse interpolation technique (IDW).These parameters were used to calculate water quality index values which were also reassigned to the GIS environment to generate the IWQI maps. The map results showed that only 25 % of the studied samples fall in Low Restriction (LR) categories indicating that this water can be used for irrigation purposes without reservation. 94 % of the groundwater was found to be moderate to highly restricted for use in irrigation and can be used only in soils with a high permeability without compact layers, requiring moderate leaching of salts. The map results also showed that 26 % of the studied water samples should be avoided and not used for irrigation under normal conditions because they fall within the Severe Restriction (SR) categories. The former type can be used only if the soil permeability is high, and the excess of water is applied to avoid the accumulation of salt.

Keywords: Irrigation Water Quality Index (IWQI), GIS, Baghdad, Iraq

1. Introduction

The entire city of Baghdad uses the waters of the Tigris River for drinking, agriculture and other purposes. In the recent years, however, the river has suffered from many problems, including scarcity of resources, construction of dams by the neighboring countries, as well as the inflow of industrial and agricultural waste water and local waste. These problems have created an urgent need to search for other water sources and assess the groundwater of the wells that are already in the area to meet the people's water needs, especially in areas located far from the river. This study is conducted to evaluate the quality of well water in Baghdad city for irrigation purposes using the irrigation water quality index (IWQI) method as well as the technology of the Geographic Information System (GIS). This approach has been successfully used in recent years and on a large scale. It provides an excellent overview of the condition of groundwater through the integration of composite data. Previously and prior to this approach, researchers used to rely on irrigation water standards set by the United States Salinity Laboratory (USSL, 1954) and Wilcox (1955) diagrams to assess water for irrigation purposes. In 2010, Meireles et al. developed an IWQI model to assess water to be used for irrigation purposes using Electrical Conductivities (EC), Magnesium (Mg^{2+}), Sodium (Na^+), Potassium (K^+), Chloride (Cl^-) and Bicarbonate (HCO_3^-) parameters, which reflect soil salinity, sodicity hazards, and water toxicity to plants. This model has been used successfully and on a large scale to assess the quality of water used for irrigation purposes by many researchers e.g. (Omran and Marwa, 2015; Al-Musawi, 2014; Rasul and Waqed, 2015; Rokbani et al., 2011; Jerome and Pius, 2010). Those researchers proved that this method is an excellent way to give an overview of the state of groundwater through the integration of composite data by summarizing the monitored data or showing the spatial distribution of quality as index allowing the best use of this water in the future. The current study is carried out with the aim of using the GIS integrated with the IWQI method which has been established by (Meireles et al., 2010) to assess the quality of groundwater, and to determine its suitability for irrigation purposes in Baghdad city.

2. Area of study

The study area lies between latitude 33° 10' to 33° 29' N, longitudes 44° 09' to 44° 33' E, the elevation of catchment area ranges from 33m to 37m above sea level covering area about 5159 km^2 (Figure 1).

The city of Baghdad is characterized by a warm and dry climate in summer and cool humidity in winter with the annual precipitation rates ranging from 0.05 mm to 24.66 mm. The monthly temperature ranges between 9.64 and 35.39 C°, while

* Corresponding author e-mail: mufidalhadithi@yahoo.com

evaporation ranges from 66.85 to 530 mm. Relative humidity has a direction compared to temperature and evaporation. Geologically, the study area is relatively simple represented by the Quaternary deposits (Pleistocene), and is covered mainly by the Holocene deposits (Jassim and Goff, 2006). Hydrogeologically, good sand aquifer has been observed underground at the depths of 8-20 m in the studied area.

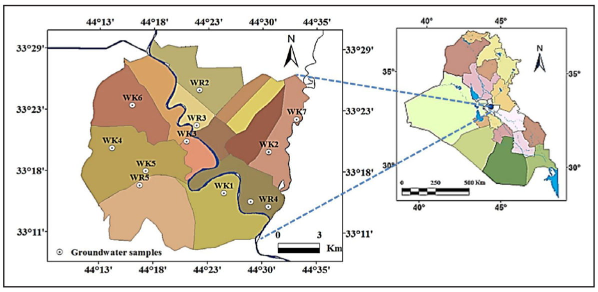

Figure 1. Location map of the study area showing sampling site

3. Methodology

3.1. Water Samples and Analysis

Twelve water samples were collected from twelve wells covering the whole area of the study analyzed by the Ministry of Science and Technology (MOST). Table 1 shows the details of the sampling locations along with their latitude and longitude. The collected samples were analyzed chemically concerning different elements including EC, Na^+, Cl, HCO_3^- ,and SAR which affect the quality of water used for irrigation purposes. These parameters have been used to calculate IWQI. EC has been measured in the field using a conductivity meter. Sodium (Na^+) has been analyzed by a flame photometer, HCO_3^{-1} and Cl^- were analyzed by H_2SO_4 and $AgNO_3$ titration methods, respectively (Jackson, 1976). All the results of the chemical analysis were summarized in Table 2.

Table 1. Sampling locations

Location	Well code	Latitude	Longitude	Elevation (m)	Depth (m)	Water level (m)
Al-Dora	WK1	33 16 58.9	44 26 37.6	35	14	20
Saidia	WK2	33 16 12.4	44 27 43.7	34	27	28
Karadha M.	WK3	33 18 50.1	44 22 20.2	32	26	28
Al-Mansour	WK4	33 19 12.4	44 24 52	33	11	12
Yarmouk	WK5	33 16 11.9	44 21 11.4	35	13	13
Shulah	WK6	33 22 17	44 17 27.0	38	22	22
Rahmania	WK7	33 21 11.1	44 21 15.1	36	20	20
Zafrania	WR1	33 14 9.7	44 28 07.7	33	15	15
Shabe	WR2	33 23 34	44 25 7.2	34	13	13
Adamia	WR3	33 21 40	44 23 18.6	34	14	14
Dyala	WR4	33 12 17	44 30 52	33	21	21
MOST	WR5	33 16 43.6	44 24 09.3	34.5	18	18

Table 2. Chemical analysis of groundwater samples in the study area (Units in meq. l-1 except EC in (μs/cm) and TDS in ppm)

Well code	pH	TDS	EC	Ca^{+2}	Mg^{+2}	K^+	Na^{+2}	HCO_3^-	Cl^-	SO_4^{-2}	Na%	SAR
WK1	7.3	2298	3800	12.97	8.22	0.11	16.30	3.33	24.8	9.9	43.6	5.01
WK2	6.9	2573	5320	16.72	14.47	0.11	13.04	6.07	30.1	6.6	29.6	3.30
WK3	7.4	1578	3100	5.49	10.20	0.08	8.61	9.84	7.8	5.5	35.6	3.07
WK4	7.2	2877	11000	17.12	15.38	0.15	12.17	3.20	18.5	25.2	27.5	3.02
WK5	7.3	970	1840	6.64	4.52	0.13	4.26	4.10	3.4	6.4	28.2	1.80
WK6	7.3	2042	2300	9.38	8.39	0.13	13.26	5.25	9.0	16.6	43.9	4.45
WK7	7.8	561	1210	2.59	2.71	0.08	2.74	2.89	2.5	3.0	34.6	1.68
WR1	7.7	786	1000	4.54	2.88	0.12	4.26	4.93	2.5	3.5	37.1	2.21
WR2	7.2	1210	1990	7.68	6.17	0.19	5.00	5.74	4.8	7.1	27.3	1.90
WR3	7.4	2228	4260	22.95	6.91	0.18	4.65	2.30	3.0	27.5	13.9	1.20
WR4	7.3	1528	2420	8.53	6.41	0.19	7.65	3.80	6.0	13.5	34.4	2.80
WR5	6.8	1901	3210	8.68	4.93	0.16	13.96	5.84	6.0	16.0	50.9	5.35

3.2. Calculation of the Irrigation Water Quality Index (IWQI)

The EC, Na^+, Cl^-, $HCO_3^-$and SAR parameters suggested by (Meireles et al., 2010) have been used to calculate the IWQI. EC, Na^+, Cl^- and HCO_3^- parameters were measured in the laboratory and (SAR) was calculated as the ratio of sodium absorption using the following equation:

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

In the first step, values of the accumulation weights (w_i) suggested by (Meireles et al., 2010) have been defined based on their relative significance to the irrigation water quality. Its normalized values and their total are equal one as shown in Table 3. Based on different parameters recommended by (Ayers and Westcot, 1994), Qi value was estimated in the second step as shown in Table 4. It represents non-dimensional number with the higher value indicating a better water quality and vice versa. Qi value was calculated using the following equation:

$$Q_i = q_{imax} - \left\{\frac{[(x_{ij} - x_{inf})* q_{iamp}]}{x_{amp}}\right\} \quad \text{.....(2)}$$

where q_{imax} is a maximal value of qi for the class, x_{ij} is the observed value of chemical parameters, x_{inf} is the 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. Finley Irrigation water quality index (IWQI) has been calculated according to the following equation:

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

where IWQI is the non-dimensional irrigation water quality index ranging 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."(Meireles et al. 2010) have divided the values of IWQI for the suitability of the irrigation water class into five dimensionless parameter classes based on the proposed groundwater quality index determined by the existing groundwater quality index as shown in Table 5. The classes were defined based on salinity hazard problems, soil water infiltration reduction, and toxicity to plants as suggested by (Bernardo, 1995). The method of calculating the irrigation water quality index was explained in details as an example of well number one (WK1) in Table 6.

Table 3. Weights for the IWQI parameters according to Meireles et al., 2010

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

Table 4. Limiting values of (qi) calculations (Ayers and Westcot, 1994).

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

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

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. Leaching recommended 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. Salt leaching recommended. 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, moderate leaching of salts suggested.	Moderate restriction (MR)	55- 70
Should be used for the 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 for irrigation under normal conditions. May be used occasionally in special cases,. Water with low salt levels and high SAR require gypsum application. In high saline water, soils must have high permeability, and excessive water should be applied to avoid salt accumulation	Severe restriction (SR)	0-40

Table 6. Calculating of the irrigation water quality index (IWQI) of the well No. 1

Chemical parameter	Xij	Class	Q_{imax}	Q_{iamp}	X_{inf}	X_{amp}	Qi	Wi	IWQI
EC	3800	4	35	35	200	10800	23.33	0.211	4.92
Na+	16.30	4	35	35	2	14.3	-0.01	0.204	0.00
HCO_3-	3.33	2	85	25	1.5	3	69.77	0.202	14.09
Cl-	24.79	4	35	35	1	29	6.29	0.194	1.22
SAR	5.01	2	85	25	3	3	68.27	0.189	12.90
								1	**33.14**

3.3. GIS Database Generation and Analysis

The results of the chemical analysis of the water samples were transferred to the GIS environment to create a water quality database in the study area, and the spatial distribution map for each parameter has been generated using the ArcGIS 10.1 software, spatial analyst extension, and inverse distance weight (IDW) interpolation methods as shown in Figures 2 to 8.

4. Results and Discussion

4.1. Salinity Hazard

Electrical Conductivity (EC) of the water samples collected from the study area has been measured, and the spatial distribution map was prepared using GIS as shown in Figure 2. In general, it could be concluded that the large variation in EC ranges from 100 µmhos/cm to 11000 µmhos/cm. This is mostly due to the dominant human activities in this area. According to Rao (1986), the high values of EC may be attributed to the reduction of the osmotic activity of the plants which interferes with the absorption of water and nutrients from the soil.

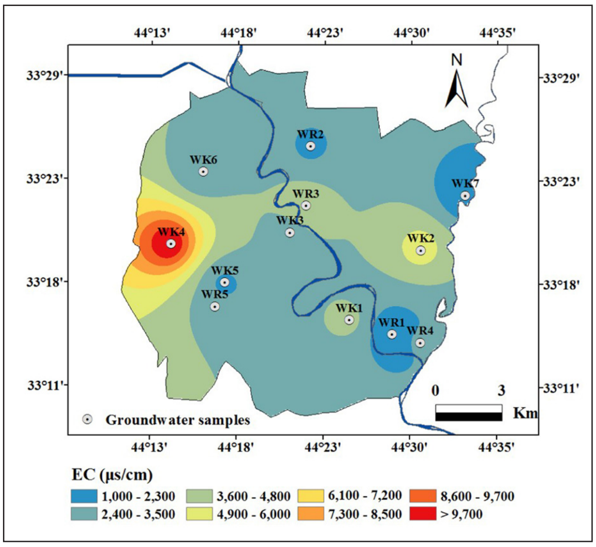

Figure 2. EC Spatial distribution map of the study area

4.2. Sodium Percentage (Na %)

The percentage of sodium is a communal factor in the evaluation of all natural waters, their appropriateness for irrigation purposes, and their influence on the physical and chemical properties of the soil. Sodium can have a great effect on the soil permeability infiltration process. When sodium is highly concentrated, the soil becomes solid, and compact when dry. This affects the structure of the soil and leads to reduce the rates of air and water leakage to the soil (USSL Staff, 1954; Tijani, 1994). In the studied water samples Na^+% values ranged between (13.9) and (50.9); the spatial distribution map of the sodium content was prepared and shown in Figure 3.

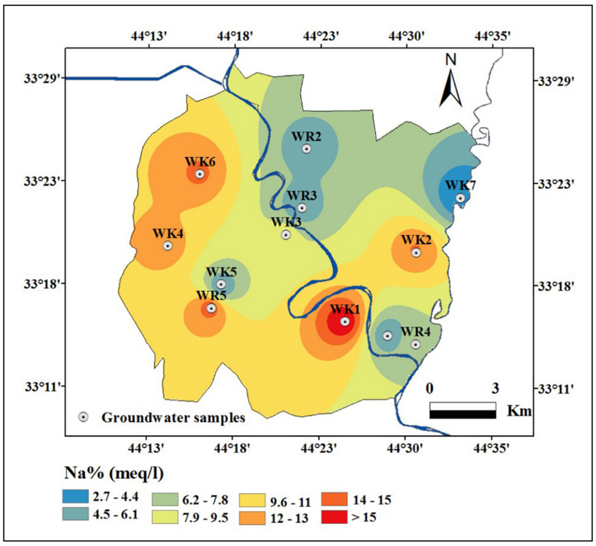

Figure 3. Na% Spatial distribution map of the study area

4.3. Alkalinity Hazard

Alkaline hazard is expressed as the ratio of sodium adsorption (SAR) which is the most common water quality factor that influences the normal rate of infiltration of water. It is calculated according to (Ayers and Westcot, 1994) as shown in equation 1. The values of SAR in the studied samples range from 1.2 meq/L to 5.01 meq/L. These values have been inputted to the GIS environment to create a spatial distribution of SAR map as displayed in Figure 4. If the value of the SAR is more than eighteen, the groundwater is considered unsuitable for irrigation purposes according to (Varol and Davraz, 2015). Based on SAR values in the studied groundwater, all the samples were found suitable for irrigation purposes.

4.4. Toxicity and Miscellaneous Effects

Chloride concentrations are presented as the parameter defining the specific ion toxicity. Although chloride ion is an influential factor in some regional water classifications, it is usually not included in modern water classifications because it does not affect the physical properties of the soil. The chemical analysis of the water samples showed that the minimum value of chloride is 2.5 meq/l (i.e 88.75 mg/l), and the maximum value is 30.1 meq/l (i.e 1068.55 mg/l) as presented in Table 1. The spatial distribution of chloride concentrations is shown in Figure 5. It has been observed that chloride concentrations were relatively high in all the water samples. Chloride is essential for plants in very low amounts, yet it can cause toxicity to sensitive crops at high concentrations. In comparison with the criteria presented in Table 7, plants were very sensitive to the amount of chloride in 33.3 % of the water samples (well no. 5, 7, 8,10), and were moderately tolerant to it in 41.7 % of the samples (well no. 11,12, 3, 9, 6). Moreover, 20 % of the water samples (well no.1, 2, 4, 10) can cause severe problems to plants as a result of the amount of chloride.

Table 7. Chloride classification of irrigation water (Bauder et al. 2003)

Chloride (mg\l)	Effect on Crops
Below 70	Generally safe for all plants
70-140	Sensitive plants show injury
141-350	Moderately tolerant plants show injury
Above 350	Can cause severe problems

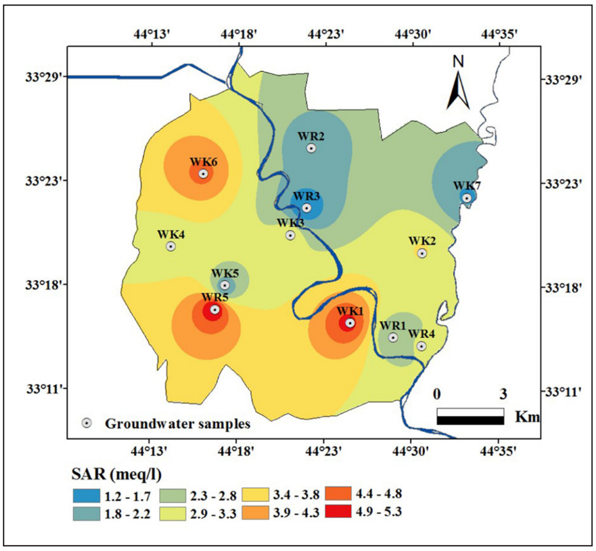

Figure 4. (SAR) Spatial distribution map of the study area

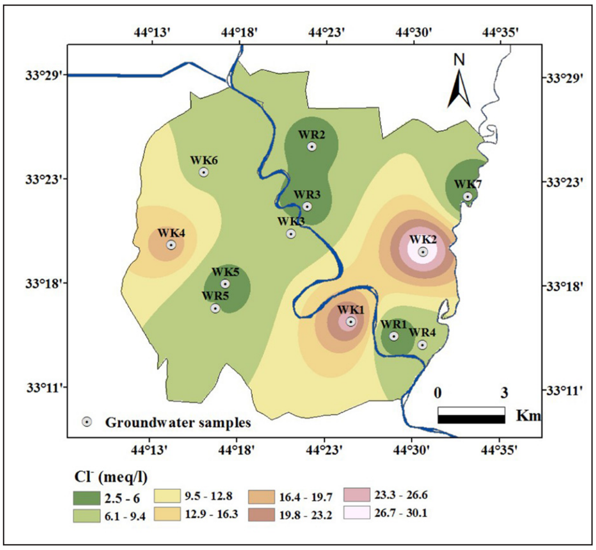

Figure 5. (Cl-) Spatial distribution map of the study area

Bicarbonate and pH parameters were found to be within the range of the miscellaneous effects on sensitive crops. The pH values range from 6.8 to 7.8 in the studied water samples as shown in Figure 6. It is found that all studied water samples were within the range reported by (Rizwan and Gurdeep, 2010) which is ranging from 6.5 to 8.4 in the irrigation groundwater. The reason for the high pH values to more than 8.5 in the groundwater are bicarbonate ions and thus can be considered the main component of alkalinity in groundwater (Charmaine and Anitha, 2010). The ability of the plant to take nutrients from the soil varies depending on the pH values. If the value of the pH is high or low it limits its ability to absorb nutrients. When the pH is low, the solubility of the ammonium and manganese salts increases and their concentration may be harmful to the plant.

Bicarbonate ion (HCO_3^-) concentration in the water samples ranged from (9.84 meq/l) to (2.3 meq/l) as shown in Figure 7. According to (Ayers and Westcot, 1994), the bicarbonate concentration values below 90 mg/l (i.e. 1.5 meq/l) are considered to be ideal for irrigation. Accordingly, all the studied samples containing more than 90 mg / L are not suitable for irrigation.

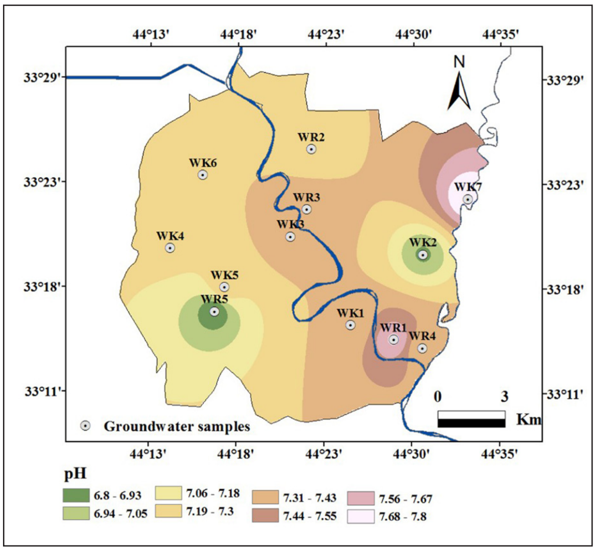

Figure 6. pH spatial distribution map of the study area

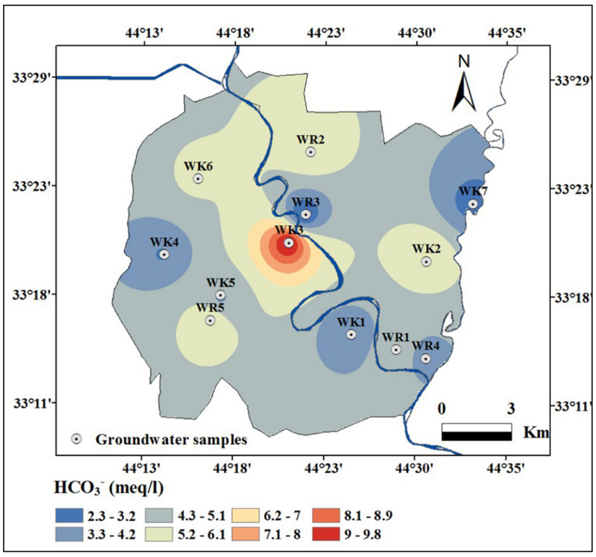

Figure 7. (HCO3-) Spatial distribution map of the study area

The spatial distribution maps of all the parameters which have been discussed above have been generated using inverse interpolation technique (IDW) to create the database of groundwater quality for irrigation water based on the data of twelve wells representing the Baghdad region. Maps of the spatial distribution of contaminant concentrations in groundwater in the study area provide a suitable presentation of the distribution of groundwater quality. Hence, these maps could be used to evaluate the groundwater quality, and estimate the suitable sites of new wells having lowest harmful pollutants.

4.5. Irrigation Water Quality Index (IWQI) Map

The EC, SAR, Na^+, Cl^- and HCO_3^- parameters have been used to calculate IWQI in the study area. Spatial distribution maps were prepared for each parameter and were integrated using ArcGIS /spatial analyst extension according to Equation (3). This integration gives the IWQI index map as a result of geostatistical analysis as shown in Figure 8.

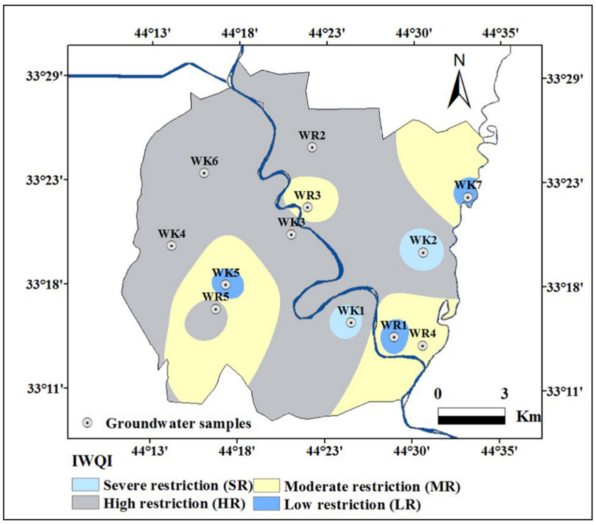

Figure 8. IWQI spatial distribution map of the study area

The analysis of IWQI map shows that the suitability of groundwater for irrigation in the studied area is divided into four classifications of water use restrictions. Only 25 % of groundwater fall in the low-restricted categories and could be used for irrigation directly without any processing. 49 % of the studied samples fall in the moderate to highly restricted for use classification, which means they can be used in soils with high permeability without compact layers, requiring moderate leaching of salts to ensure no harm to plants. The remaining (26 %) of the studied samples fall in the severe restriction (SR) categories, which means that this water should be avoided, and not used for irrigation under normal conditions. However, this water can sometimes be used if the soil permeability is high, and the excess of water is applied to avoid the accumulation of salt.

5. Conclusions

The integration of the spatial distribution map of EC, SAR, Na^+, Cl^- and HCO_3^- parameters have been conducted using the GIS technique to give the IWQI index map as a result of geostatistical analysis. Since the map shows the spatial distribution of the quality of irrigation water in the plain as index values, it provides a comprehensive view, and gives the results concerning the state of the groundwater. This facilitates the task of decision makers to assess the quality of groundwater used for irrigation in the study area. An analysis of the results of the IWQI maps confirms that 25 % of the groundwater in the study area is found to be suitable for irrigation purposes.

References

AL-Musawi, W.H. (2014). Assessment of Groundwater Quality in UMM ER Radhuma Aquifer (Iraqi Western Desert) by Integration between Irrigation Water Quality Index and GIS, Report submitted by Civil Engineering, University of Karbala, Iraq.

Ayers, R.S., and Westcot, D.W. (1994). Water quality for agriculture: FAO Irrigation and Drainage Paper 29, Revision 1, 1-130.

Bernardo, S. (1995). Manual de Irrigacao, 4th edition, Vicosa: UFV, 488 p.

Bauder, T.A., Waskom, R.M., Sutherland, P.L., Davis, J.G. (2003). Irrigation water quality criteria – 0.506, Colorado State University.

Charmaine, K.S.J., and Anitha, P. (2010). Evaluation of water quality index and its impact on the quality of life in an industrial area in Bangalore, American Journal of Scientific and Industrial Research, 1(3): 595-603.

Jackson, M.L. (1976). Soil Chemical Analysis. Prentice Hall Inc. Englewood Cliffs, NJ, USA, 227-267.

Jassim, S.Z., and Goff, J.C. (2006). Geology of Iraq, Dolin Prague and Moravian Museum, Brno, 341p.

Jerome, C., and Pius, A. (2010). Evaluation of water quality index and its impact on the quality of life in an industrial area in Bangalore, South India, American, Journal of Scientific and Industrial Research, 1 (3): 595-603.

Meireles, A., Andrade, E.M., Chaves, L., Frischkorn, H., Crisostomo, L.A. (2010). A new proposal of the classification of irrigation water, Revista Ciencia A gronomica, 41(3): 349-357.

Omran, I., and Marwa, F. (2015). Evaluation of Drainage Water Quality for Irrigation by Integration between Irrigation Water Quality Index and GIS, International Journal of Technical Research and Applications, 3(4): 24 – 32.

Rao, N.S. (1986). Hydrogeology and hydrogeochemistry of Visakhapatanam. Ph.D Thesis unpublished.

Rasul, M.K., and Waqed, H.H. (2015). Evaluation of irrigation water quality index (IWQI) for al-dammam confined aquifer in the west and southwest of karbala city, iraq, International Journal of Civil Engineering (IJCE), 2(3): 21-34

Rizwan, R., and Gurdeep, S. (2010). Assessment of Ground Water Quality Status by Using Water Quality Index Method in Orissa, India, World Applied Sciences Journal, 9(2): 1392-1397.

Rokbani, M.K., Gueddari N., Bouhlila, R. (2011). Use of Geographical Information System and Water Quality Index to Assess Groundwater Quality in El Khairat Deep Aquifer (Enfidha, Tunisian Sahel), Iranica Journal of Energy and Environment, 2(2): 133-144.

Tijani, M.N. (1994). Hydrochemical assessment of groundwater in Moro Area, Kwara State, Nigeria. Environmental Geology, 24:194–202.

United State Salinity Laboratory Staff. (1954). Diagnosis and improvement of saline and alkali soils. USDA Agr Handbook No. 60, Washington DC.

Varol, S., and Davraz, A. (2015). Evaluation of the groundwater quality with WQI (Water Quality Index) and multivariate analysis: a case study of the Tefenni plain (Burdur/Turkey), Environmental Earth Science, 73: 1725–1744.

Wilcox, L.V. (1955). Classification and use of irrigation water, U.S.A Dept. Ag. Circ. 696, Washington DC. 19p.