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SPATIAL VARIATION OF GROUNDWATER QUALITY BY USING GIS - EAST OF THE THARTHAR LAKE AREA, IRAQ: A CASE STUDY

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ABSTRACT
Study area is located to the east of the Tharthar Lake (Iraq) and covers an area about 4035 Km^2. Groundwater is the most important source in the area except the area in the east, which is, depended on the Tigris River. For studying the suitability of groundwater, chemical analyses for 42 wells have been used. ArcGIS software has been used to build rasters form wells data for required chemical elements and to calculate the suitability by using Map Algebra (Map Calculator). For drinking water, WHO and Iraqi drinking water standards have been used to calculate the suitability of water for drinking. The suitability for drinking water shows small area (11.94 Km^2) in the east of river while the whole area is unsuitable. For irrigation suitability, two methods have been used to classify the water suitability, Richards (1954) methods, and Ayers and Westcot (1985), and Wilcox (1955) method. Richards (1954) method shows an area (90 Km^2) with permissible water type, while Ayers and Westcot (1985), and Wilcox (1955) method shows an area (451 Km^2) with good water type. The Limitation of area of suitability of water for drinking and irrigation reflects the impact of the river in enhancing the quality of ground water, while the whole area with unsuitable reflects the impact of lithology and arid climate.

KEYWORDS: GIS, Groundwater, Irrigation, Drinking, Modeling, Iraq.

INTRODUTION

Water is one of the greatest divine gifts in nature. Water is the main source of human survival. It is essential for drinking, household use, agriculture, industry, energy, navigation and other uses. There are many sources of water, whether it is superficial or ground. Groundwater is an important source in arid and semi-arid regions and the areas with limited surface water resources, so it is the second important source of water which is covering human needs. This importance has encouraged the development of technologies for detection, treatment and protection of groundwater. Groundwater is defined as the water that is found in the pores and fractures of the rocks, and accumulated in the aquifers, whether they are confined or unconfined. The recharge source of groundwater varies from meteoric, surface and magmatic water (Juvenile) (Harter, 2003). The chemical properties of the groundwater vary from place to place depending on the type of rocks of aquifer and the soluble minerals in these rocks, as well as the infiltration and leakage of pollutants of fertilizers, pesticides, industrial and household into groundwater aquifers through rainwater or surface water (Kortatsi, *et al*., 2008). Groundwater has raised the interest of researchers, institutions and organizations in various fields. Several studies have emerged, including studies that have studied the chemical and physical properties of groundwater for different uses such as drinking, agriculture and industry.

A study of Joshi and his colleagues (2009) focused on estimating the suitability of water for irrigation in the Kanga River and analyzed a range of chemical and physical elements including electroconductivity (EC), total dissolved salts (TDS), magnesium content, soluble sodium percentage (SSP), sodium adsorption ratio (SAR) and the permeability index (PI). The study was conducted in two seasons and showed salinity in the river with the rainy season due to increased solubility.

In 2009, Islam and his colleague (2009) conducted a study to estimate groundwater suitability for irrigation purposes in the province of Pokhara, Bangladesh. They relied on electroconductivity (EC), total dissolved salts (TDS), magnesium content, soluble sodium percentage (SSP) and sodium adsorption rate for water quality. Vasanthavigar and his colleagues (2010) implemented a study on the groundwater in a sub-basin through the application of the Water Quality Index. They evaluated water for irrigation and agriculture by using Soluble Sodium Percentage (SSP) and sodium adsorption rartio (SAR). The results show unsuitability of water in all seasons. Phocaides (2007) who is a consultant in Food and Agriculture Organization (FAO), pointed out the efficiency of the adoption of the E, TDS, magnesium content, Soluble Sodium Percentage (SSP) and sodium adsorption (SAR) as effective criteria for determining water quality for irrigation because of the direct risk of these elements on plants. These studies were based on the evaluation of the water quality, whether it is ground or surface water, by analyzing chemical elements from collecting samples, regardless of spatial analysis to know the distribution areas and other factors that can have a significant impact on the quality of water such as topography and geology (Lithology) *etc*.

The present study deals with the study of the chemical properties of groundwater in the East of Tharthar Lake. The problem of the study was the high concentration of salts in agricultural soils based on groundwater. These areas are characterized by limited surface water resources and depend on groundwater for various purposes. The aim of the study is to determine the quality of groundwater and its suitability for drinking and irrigation use, and determine the spatial distribution of potential suitable groundwater occurrences by using GIS techniques.

Study Area

The study area is located in the central part of Iraq to the north of the Baghdad at a distance of 120 km, between the Tigris River and Samarra from the east and the Tharthar Lake from the west. It is bounded by latitudes 35˚ 00’38" and 35˚ 34’48" north and longitude 43° 04’ 12" and 44˚ 10 '18" east and covered an area of 4035 km2 Fig.1.

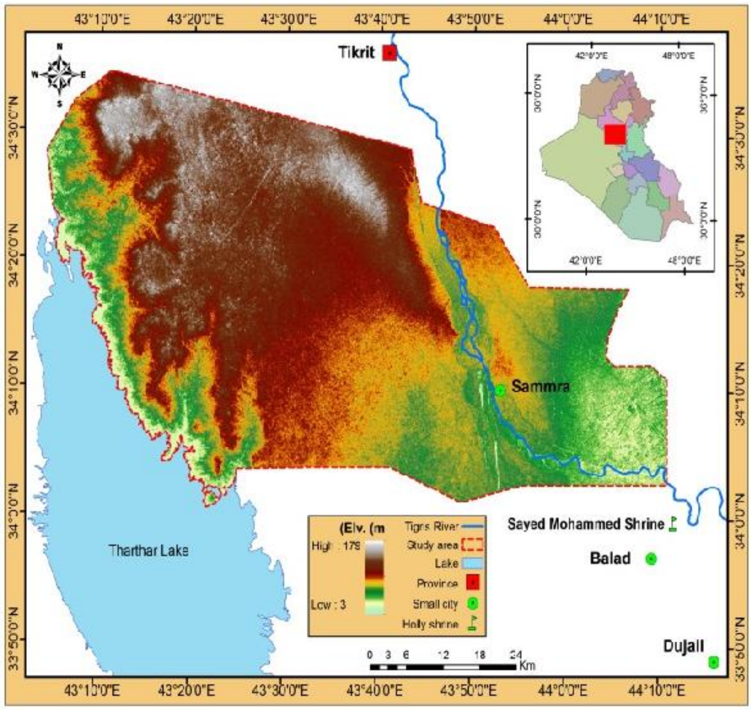

FIGURE 1: Study area.

Source: USGS (2004). Shuttle Radar Topography Mission, 3-Arc Second scenes for IRAQ, Unfilled Unfinished 2.0, Global Land Cover Facility, University of Maryland, College Park, Maryland, February 2000.

Geology of the study area contains various formations of different ages (Tertiary and Quaternary deposits). It consists mainly layers of claystone, limestone, gypsum and anhydrite with a thickness of up to 12 m of Injana formation followed by (300-1200 m) thickness of Mukdadia and Bai-Hassan Formations that consists sequence of sandstone, limestone and claystone, as well as conglomerate and gravels. The Quaternary sediments are the sediments of the alluvial fans, gypcrete, shop deposits, and flood plain deposits, which area fragmented, permeable and rich with gypsum (Ahmed and Al-Jiburi, 2005), (Mahmoud and Ahmed, 1986). The temperature in the study area rises especially in the summer to reach at Samarra station to 44 ° C (Max.) for July, corresponding to 4.9 ° C (Min.) in January with annual rate of 30.5° C (Max.) and 16.5° C (Min.) The annual rainfall about 171.5 mm in winter and becomes very rare in the summer. Evaporation values are very high at 3085.6 mm per year because of the long-lasting of summer which is characterized by rising of temperature and rarity of rainfall which are the characteristics of arid and semi-arid climate (MOT, 2014).

MATERIALS &METHODOLOGY

The chemical analysis of collected samples (42 wells) distributed overall the study area was Appendix 1. The chemical analyzes included the electrical conductivity (Ec) (µS/ cm), total soluble salts (TDS)), Sodium (Na), magnesium (Mg), calcium (Ca), chloride (Cl) and sulphate (SO4), all measured in milligrams / l (Table 1). The units of elements (K), (Na), (Mg), (Ca), (Cl) and (SO4) were converted to (Meq /l) using Aquachem 4.0 software Appendix 2, to meet the Calculation Sodium Absorption Ratio (SAR) and Soluble Sodium Percentage (SSP). The sites of the wells are projected according to their coordinates by ArcGIS 10.x software in the form of points map Fig.2, and then the chemical properties joined in the attribute table.

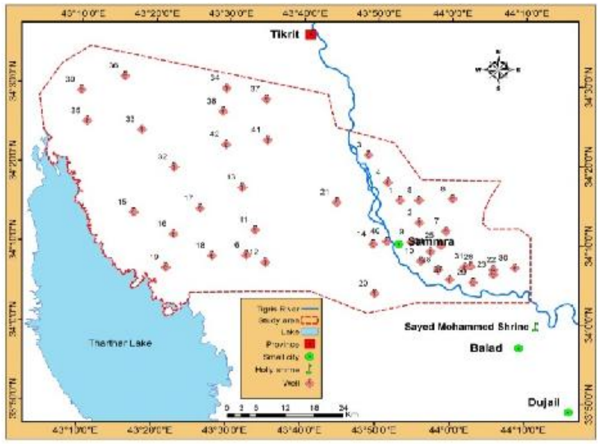

FIGURE 2: The wells in the study area.
Source: Appendix 1 by using ArcGIS 10.x

Suitability for drinking

It was adopted in the calculation of the suitability of water for human use on the Iraqi water quality standards (Table 3). Fig. 3 shows the flowchart of methodology to extract and plot potential zones for the presence of groundwater which suitable for human consumption and irrigation. First step is by convert chemical element from point well map into a RASTER or a surface in the ArcGIS using the IDW Interpolation method and then using ArcGIS- Map Algebra in order to calculate suitability according to the criteria and the standard for drinking and irrigation. Fig. 4-9 show the elements are required to calculate the spatial destruction for drinking ground.

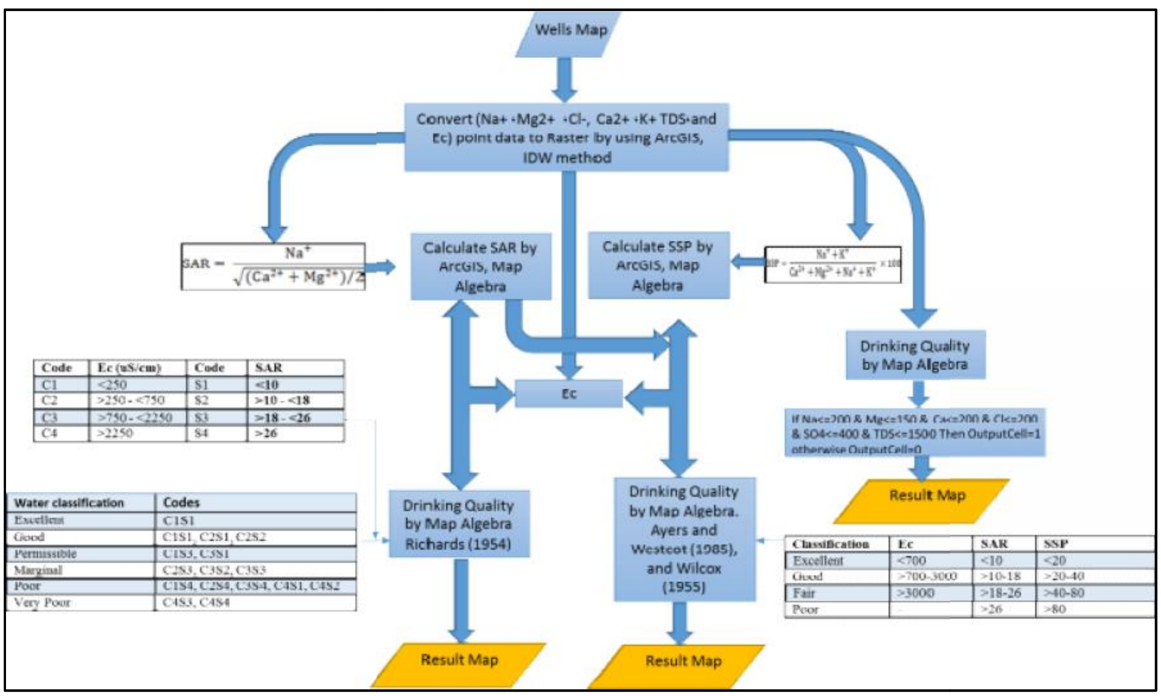

FIGURE 3: Flowchart of Methodology

TABLE 1: WHO and Iraqi drinking water standards.

Elements	(WHO) Standard		Iraqi Statndard
	Min.	Max.	
Na^{+}	-	-	200
Mg^{2+}	20	150	150
Ca^{2+}	75	200	200
Cl^{-}	200	600	600
$SO4^{2-}$	200	400	400
TDS	500	1500	1500

Source: WHO. 1971., International Standard for Drinking Water, 3rd Ed., Geneva, Switzerland.

1- Al-Dabbaj, A.A. and Al-Khashab, S.N., 2000. Hydrogeological and hydrochemical study of Al-Salman Quadrangle, sheet NH-38-6, scale 1: 250 000. int. rep. no. 2701(unpublished). GEOSURV, Baghdad, Iraq.

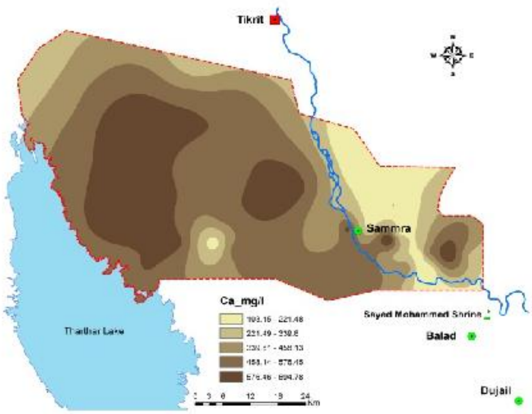

FIGURE 4: Raster of Calcium (mg/l)

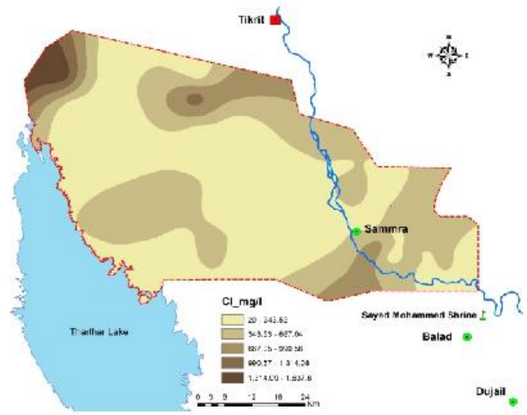

FIGURE 5:: Cloride of Calsium (mg/l)

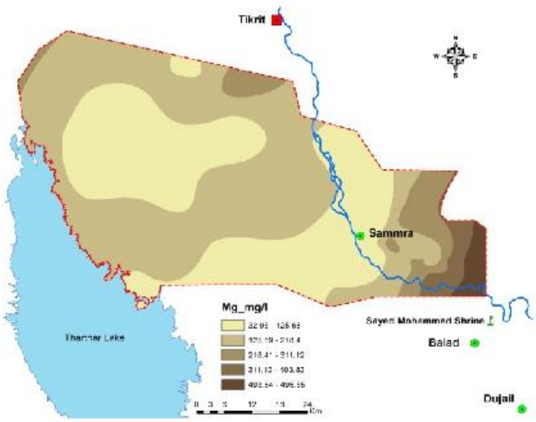

FIGURE 6:: Magnisium of Calsium (mg/l)

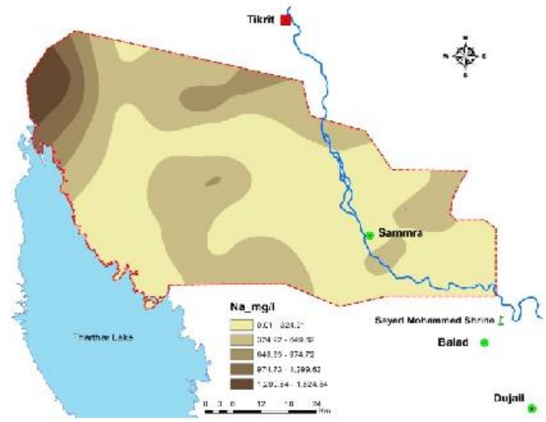

FIGURE 7:: Raster of Sodium (mg/l)

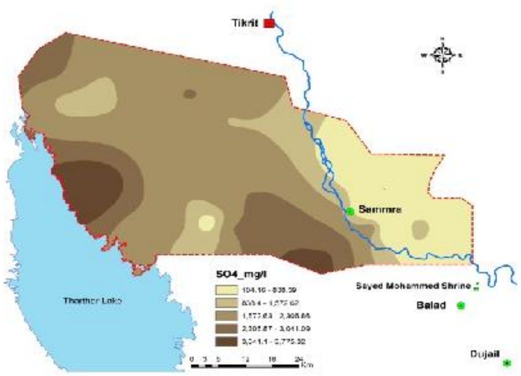

FIGURE 8: Raster of Sulfate (mg/l)

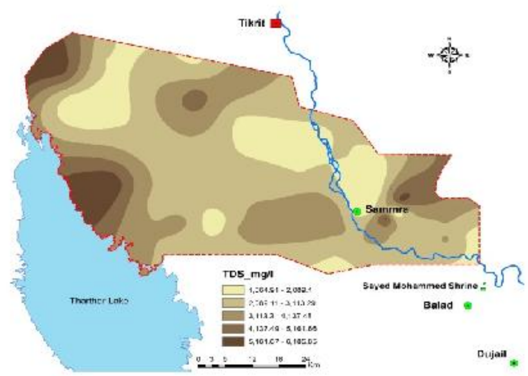

FIGURE 9:: Raster of TDS (mg/l)

Suitability for agriculture

Two methods have been adopted to calculate the suitability for agricultural irrigation purposes, as follows:

Richards (1954) method: This method is based on the calculation of sodium adsorption rate (SAR) and electrical conductivity (Ec). SAR is calculated from the following equation:

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

The elements used in the formula of SAR must be in (meq/l).The groundwater quality code is determined according to Ec and SAR Table 2.

After the identification of the codes for the sample, the suitability of the groundwater for irrigation classified accordingly to five categories of groundwater quality types Table 3.

TABLE 2: Codes of SAR and Ec

Code	Ec (uS/cm)	Code	SAR
C1	<250	S1	<10
C2	>250 - <750	S2	>10 - <18
C3	>750 - <2250	S3	>18 - <26
C4	>2250	S4	>26

Source: After (Richards. 1954)

TABLE 3: Classification of groundwater according to Richards (1954)

classification	Codes
Excellent	C1S1
Good	C1S1, C2S1, C2S2
Permissible	C1S3, C3S1
Marginal	C2S3, C3S2, C3S3
Poor	C1S4, C2S4, C3S4, C4S1, C4S2
Very Poor	C4S3, C4S4

Source: After (Richards. 1954)

1. **Ayers and Westcot (1985), and Wilcox (1955) method**: This method is based on three elements: (Ec), (SAR) and the Soluble Sodium Percentage (SSP). The SSP is calculated from the following equation: Which requires the elements be in units (meq/l) also (Todd, 1980).

$$SSP = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100$$

The type of water and its suitability for agricultural irrigation are determined from Table 4. Ayers and Westcot (1985), and Wilcox (1955) identified four categories of groundwater quality types for agricultural purposes.

TABLE 4: Classification of groundwater according to Ayers and Westcot (1985), and Wilcox (1955)

Classification	Ec	SAR	SSP
Excellent	<700	<10	<20
Good	>700-3000	>10-18	>20-40
Fair	>3000	>18-26	>40-80
Poor	-	>26	>80

Source:

1- Wilcox, L.V. 1955. Classification and use of irrigation water, U.S. Department of Agriculture, Circular No. 969, Washington D.C. U.S.A., pp. 1-19.
2- Ayers, R.S. and Westcot, D.W. 1985. Water quality for agriculture. irrigation and drainage, Paper No. 29, Food and Agriculture Organization of the United Nations, Rome, Italy,p. 8.

The chemical elements have been converted to interpolated raster by using same method Fig. 10-13 which are required to calculate SAR and SSP (Fig.14 &15) in addition to Ec Fig. 16.

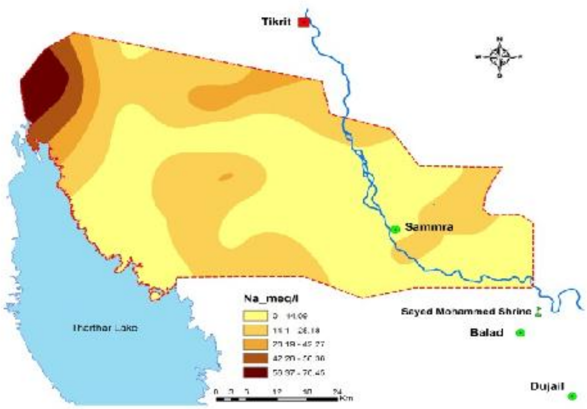

FIGURE 10: Raster of Sodium (meq/l)

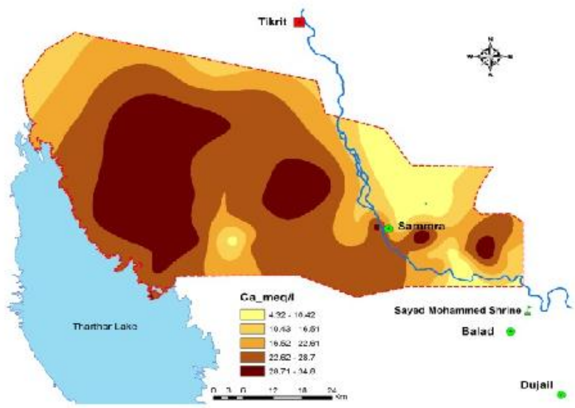

FIGURE11: Raster of Clacium (meq/l)

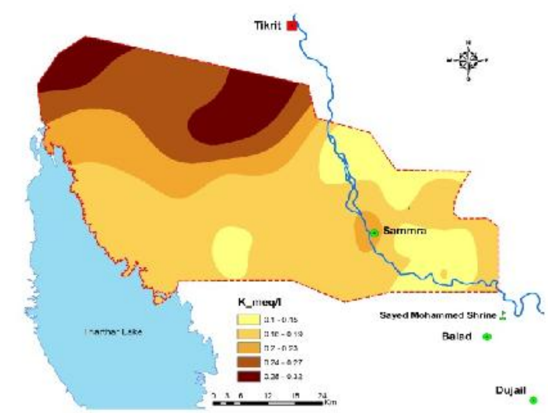

FIGURE 12: Raster of Potassium (meq/l)

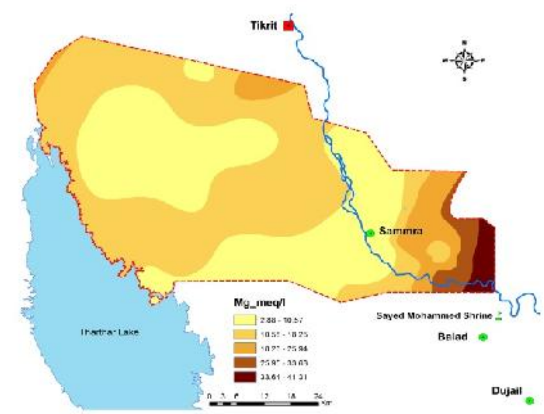

FIGURE 13: Raster of Magnesium (meq/l)

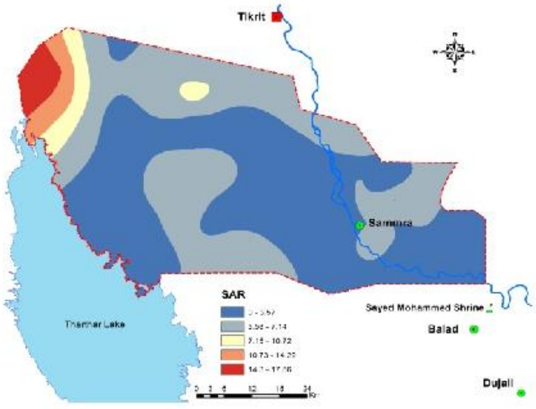

FIGURE 14: Raster of SAR

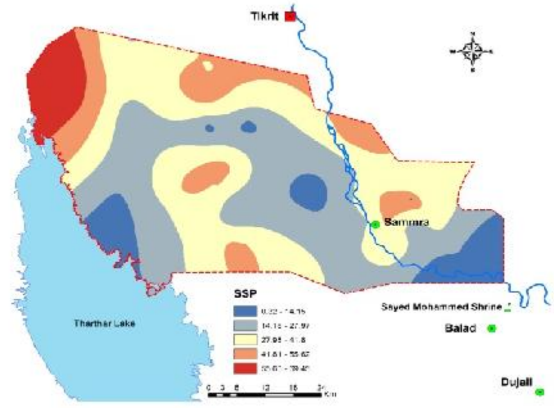

FIGURE 15: Raster of SSP

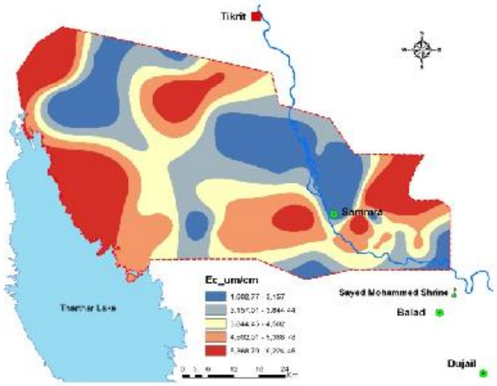

FIGURE 16: Raster of Ec (uS/cm)

The spatial variation of groundwater quality and suitability for human and agricultural uses in the study have been calculated and presented in spatial map for drinking, irrigation Richards (1954) method and irrigation Ayers and Westcot (1985), and Wilcox (1955) method by using Map Algebra in ArcGIS 10.x Fig.17-19

RESULT & DISCUSSION

The majority type of groundwater in the study area is dominated by calcium, magnesium, sulfate and sodium elements. This reflects the effect of the lithology of aquifers on the concentration of these elements by dissolving limestone, dolomite, anhydrite and gypsum of Tertiary formations, which is composed of calcium, magnesium and sulfate.

The spatial variation of the potential groundwater occurrence for human use shows very limited regions with an area of 11.94 km2 only which are located to the east of the river Tigris and near the district of Samarra Fig.17. This rarity of good groundwater might due to the high proportion of chemical elements from the permissible limits which are a result of solution from calcareous and evaporates rocks where this groundwater is located.

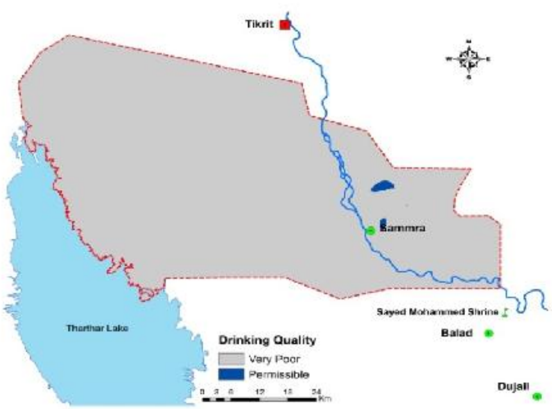

FIGURE17: Spatial variation of groundwater quality for drinking.

Groundwater for irrigation purposes according to the Richards method Fig.18 shows three types of groundwater which are permissible water C3S1 with an area of 90 km 2 in the east of the Tigris river and the north of the study area and two types of poor water C4S1 in most of the study area (3721 km2) and C4S2 with an area of 224 km2 in the northwest of the study area and north of Tharthar Lake. This reflects the limited potential areas for the presence of irrigated water according to this classification.

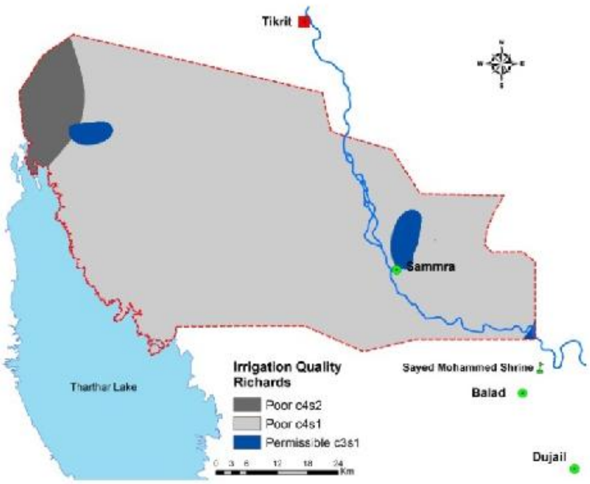

FIGURE18: Spatial variation of groundwater quality for irrigation, Richards (1954).

While groundwater quality for agricultural irrigation according to Ayers and Westcot (1985) and Wilcox (1955), shows three types of water: 451 km2 of good water distributed in the east and west of the Tigris River and 782 km2 of fair groundwater the north and west study area and poor water area 2802 km2 in the most of study area Fig.19.

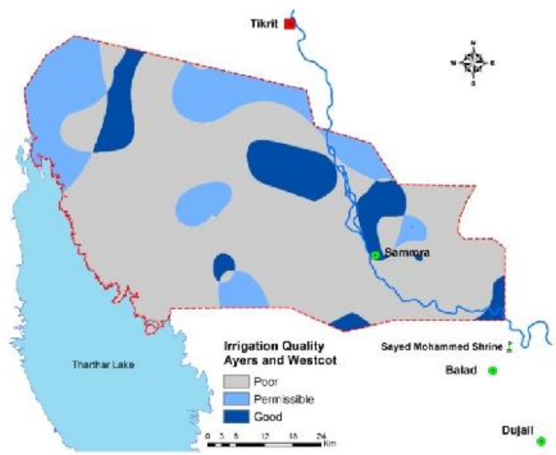

FIGURE19: Spatial variation of groundwater quality for irrigation, Ayers and Westcot (1985) and Wilcox (1955).

CONCLUSION

The study of the quality of groundwater for human and agricultural consumption shows the potential occurrence in small areas for those purposes. This spatial limitation of suitable groundwater due to dissolving action of these water to the minerals of rocks of its aquifers, especially aquifers which are located within calcareous and evaporates rocks of Tertiary which are consist mainly of calcium, Magnesium, and sulfate. These minerals are highly soluble with water. The good and permissible water areas located in the east of the Tigris River near the district of Samarra. This reflects the impact of the river on the quality of this ground water in those areas in contrast to the high areas to the west or the right of the Tigris River towards the Tharthar Lake, as the river has no impact because of the elevation. The rare of rainfall rates is another factor in increasing salinity concentrations and decreasing water quality. For the irrigation methods, they show different results which is due to the differences in the factors that are used for assessment the water quality and the differences in the water types classification. Like this differences need be investigated by filed and Lab to select better method.

Appendix 1: Location and chemical analysis of groundwater samples

Well No.	Lat.	Long.	Mg/l							uS/cm
			SO4	**CI**	**Ca**	**Mg**	**Na**	**K**	**TDS**	Ec
1	43.88	34.26	319	567	180	118	160	8.1	1500	**2270**
2	43.93	34.21	688	213	124	54	298	5.5	1514	**2260**
3	43.81	34.35	760	515	220	104	360	3	2084	**3110**
4	43.86	34.30	198	314.2	179.1	98	204	5	2092	**3122**
5	43.93	34.26	386	155	130	82	123	2	1329	**1984**
6	43.54	34.14	519	567	180	118	260	3.2	1521	**2270**
7	43.99	34.20	306	591	195.5	274.5	494.5	8.2	5313	**7930**
8	44.00	34.26	241	367	185.7	225.4	328.8	6.8	3584	**5350**
9	43.91	34.17	193	310	180	40	115	7.8	1272	**1899**
10	43.93	34.13	1978	788	488	75	426	5.5	3698	**5520**
11	43.56	34.19	2016	117	512	150	184	6.6	2732	**4077**
12	43.59	34.13	2131	198	472	102	522	6.8	2945	**4396**
13	43.53	34.28	1833	275	468	144	649	6.3	2412	**3600**
14	43.83	34.17	1912	125	345	90	152	4.7	3781	**5644**
15	43.29	34.23	3730	423	600	132	152	6	5816	**8680**
16	43.38	34.18	2297	557	598	193	275	6.8	3059	**4566**
17	43.44	34.24	1798	533	599	94	623	7.3	2680	**4000**
18	43.47	34.14	1949	186	584	154	414	7.2	3203	**4781**
19	43.36	34.11	1762	207	574	135	187	6.9	3269	**4879**
20	43.83	34.06	3100	664	489	125	245	6.5	2090	**3120**
21	43.74	34.25	1747	149	616	176	147	5.8	2137	**3190**
22	44.10	34.12	226	409	651	345	175	3.6	3069	**4580**
23	44.10	34.10	226	410	574	321	179	3.4	3182	**4750**
24	43.95	34.15	306	591	695.7	274.5	494.5	3.2	5313	**7930**
25	43.98	34.16	282	282	200	132.6	132	3.1	1500	**2380**
26	44.03	34.12	590	520	156	223	181	3.7	3060	**4567**
27	44.00	34.09	623.2	518	405.4	211	182	3.1	3028	**4520**
28	43.97	34.11	262	208	317.4	200.9	217.5	8.2	3028	**4520**
29	44.05	34.09	520	211	109	337	10	7.16	2372	**3540**
30	44.14	34.12	478	208	345	433	8	7.22	2191	**3270**
31	44.05	34.12	1344	330	432	135	212	7.8	2405	**3589**
32	43.38	34.32	1830	200	619	63	287	8.9	2412	**3600**
33	43.30	34.40	1565	43	608	44	250	8.8	1722	**2570**
34	43.49	34.49	1766	160	320	121	403	9.5	2352	**3510**
35	43.18	34.42	1455	145	406	150	1120	8.4	1608	**2400**
36	43.26	34.51	1689	167	420	166	412	10.2	2178	**3250**
37	43.58	34.47	2269	781	432	254	713	12.7	3676	**5486**
38	43.48	34.44	2350	1100	520	200	874	10.4	4348	**6490**
39	43.17	34.48	2420	1491	336	185	1389	11.8	5233	**7810**
40	43.86	34.17	1725	284	600	83	311	11	2398	**3579**
41	43.59	34.38	1574	142	560	80	120	11.4	2124	**3170**
42	43.49	34.37	1800	165	590	95	122	12	3655	**5455**

Source: MOWR (Ministry of Water Resources). 2016. Chemical analysis of Groundwater in Samarra Area. Commission of Groundwater, Dept. of Studies and Investigations, Baghdad, Iraq.

Appendix 2: Chemical elements in (meq/l)

Well No.	Meq/l					Water Type
	SO4	**Ca**	**Mg**	**Na**	**K**	
1	10.81	9	9.83	11.3	0.21	Na-Mg-Ca-Cl-SO4
2	14.33	6.2	4.5	12.96	0.14	Na-Ca-SO4-Cl-CO3
3	15.83	11	8.67	15.65	0.08	Na-Ca-Mg-SO4-Cl-CO3
4	4.13	8.96	8.17	8.87	0.13	Ca-Na-Mg-Cl-CO3
5	12.21	6.5	6.83	5.35	0.05	Mg-Ca-Na-SO4-CO3-Cl
6	10.81	9	9.83	11.3	0.08	Na-Mg-Ca-Cl-SO4-CO3
7	6.38	9.78	22.88	21.5	0.21	Mg-Na-Cl-CO3
8	5.02	9.29	18.78	14.3	0.17	Mg-Na-Ca-Cl
9	4.02	9	3.33	9.35	0.2	Na-Ca-Cl-CO3
10	41.21	24.4	6.25	18.52	0.14	Ca-Na-SO4-Cl
11	42	25.6	12.5	8	0.17	Ca-Mg-SO4
12	44.4	23.6	8.5	22.7	0.17	Ca-Na-SO4
13	38.19	23.4	12	28.22	0.16	Na-Ca-Mg-SO4
14	39.83	17.25	7.5	6.61	0.12	Ca-SO4
15	77.71	30	11	6.61	0.15	Ca-SO4
16	47.85	29.9	16.08	11.96	0.17	Ca-Mg-SO4-Cl
17	37.46	29.95	7.83	27.09	0.19	Ca-Na-SO4-Cl
18	40.6	29.2	12.83	18	0.18	Ca-Na-Mg-SO4
19	36.71	28.7	11.25	8.13	0.18	Ca-Mg-SO4
20	64.58	24.45	10.42	10.65	0.17	Ca-SO4-Cl
21	36.4	30.8	14.67	6.39	0.15	Ca-Mg-SO4
22	4.71	32.55	28.75	7.61	0.09	Ca-Mg-Cl
23	4.71	28.7	26.75	7.78	0.09	Ca-Mg-Cl
24	6.38	34.79	22.88	21.5	0.08	Ca-Mg-Na-Cl
25	5.88	25.07	19.38	14.43	0.08	Ca-Mg-Na-
26	12.29	7.8	18.58	7.87	0.09	Mg-Cl-SO4-CO3
27	12.98	20.27	17.58	7.91	0.08	Ca-Mg-Cl-SO4-CO3
28	5.46	15.87	16.74	9.46	0.21	Mg-Ca-Na-
29	10.83	5.45	28.08	0.43	0.18	Mg-CO3-SO4-HCO3
30	9.96	17.25	36.08	0.35	0.19	Mg-Ca-SO4
31	28	21.6	11.25	9.22	0.2	Ca-Mg-Na-SO4-Cl
32	38.13	30.95	5.25	12.48	0.23	Ca-Na-SO4
33	32.6	30.4	3.67	10.87	0.23	Ca-Na-SO4
34	36.79	16	10.08	17.52	0.24	Na-Ca-Mg-SO4
35	30.31	20.3	12.5	48.7	0.22	Na-Ca-Mg-SO4
36	35.19	21	13.83	17.91	0.26	Ca-Na-Mg-SO4
37	47.27	21.6	21.17	31	0.33	Na-Ca-Mg-SO4-Cl
38	48.96	26	16.67	38	0.27	Na-Ca-SO4-Cl
39	50.42	16.8	15.42	60.39	0.3	Na-SO4-Cl
40	35.94	30	6.92	13.52	0.28	Ca-Na-SO4
41	32.79	28	6.67	5.22	0.29	Ca-SO4
42	37.5	29.5	7.92	5.3	0.31	Ca-SO4

Source: Appendix 1 by using AquaChem 4.

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