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EVALUATION OF GROUNDWATER QUALITY FOR DRINKING PURPOSE IN BASRAHGOVERNORATE BY USING APPLICATION OF WATER QUALITY INDEX

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ABSTRACT

This study aims to apply Water Quality Index (WQI) to evaluate quality of groundwater samples collected from Basrah governorate south of Iraq. The samples were collected from (29) wells located in different districts of Basrah governorate (Safwan, Zubair, and Um-Qasr) during Summer Season of 2015. The groundwater samples were analyzed for pH, electrical conductivity, total dissolved solids and other major ions. For calculating WQI, eleven parameters; pH, EC, TDS, Total hardness as $CaCO_3$, Calcium, Magnesium, Sulphate, Chloride, Nitrate, Sodium, and Potassium have been considered. The suitability of groundwater in the study area for human drinking purpose was achieved by WQI depending on guideline values of World Health Organization (WHO 2011) for chemical parameters. Then, the weights (W_i) were assigned to the parameters based on their influence on human health. The results showed that the (WQI) values for the groundwater of study area varied from poor to unsuitable for human drinking purpose.

KEYWORD: Evaluation; Groundwater; Water quality index

تقييم نوعية المياه الجوفية لأغراض الشرب في محافظة البصرة باستخدام تطبيق مؤشر جودة المياه

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الخلاصة

تهدف الدراسة الحالية إلى تطبيق مؤشر جودة المياه (WQI) لتقييم عينات المياه الجوفية في محافظة البصرة جنوب العراق. تم جمع العينات في موسم الصيف لعام 2015 من (29) بئرا من أقضية مختلفة (سفوان، الزبير و أم قصر) في محافظة البصرة . تم تحليل عينات المياه الجوفية كيميائياً من حيث درجة الحموضة ، التوصيل الكهربائي، المواد الصلبة الكلية والايونات الرئيسية . لحساب مؤشر نوعية المياه (WQI) ، تم الأخذ بنظر الاعتبار احد عشر محددا وهي درجة الحموضة (PH) ، المواد الصلبة الكلية (TDS) ، التوصيلية الكهربائية (EC)، العسره الكلية بدلالة كاربونات الكالسيوم $CACO_3$ ، الكالسيوم، المغنيسيوم، الصوديوم، البوتاسيوم ، الكبريتات ، الكلوريدات ، النترات لغرض النظر فيها . وقد تحققت ملائمة المياه الجوفية (WQI) في منطقة الدراسة لغرض الشرب البشري اعتمادا على القيم الإرشادية لمنظمة الصحة العالمية (WHO) للمعاملات الكيميائية التي تم اعتمادها. و قد تم تعيين وزن (WI) للمعاملات على أساس مدى تأثيرها الملحوظ على صحة الإنسان إلى حد كبير . أظهرت نتائج الدراسة إن (WQI) للمياه الجوفية لمنطقة الدراسة تتراوح من رديئة إلى غير مناسبة لأغراض شرب الإنسان.

1. INTRODUCTION

Water in all types is important for the life especially human's life. Groundwater is one of the most popular resources for human activities like drinking, domestic uses, industrial, construction, and irrigation. Groundwater has many features to make it better than surface water from numerous aspects. Generally, groundwater has a good quality, and it is protected well from potential sources of pollution and less prone to seasonal variations. The development and increase of human's activities caused contamination of this water resource. Therefore, evaluation of groundwater resource quality is very important to ensure the safe use of water. WQI is defined as rating technique, which provides the composite influences of individual water quality parameter on the overall quality of water. It is used to reduce a large amount of water quality parameters to a single numerical value (Mahmood et al., 2013).

Water quality and its suitability for drinking purposes can be examined by determining its quality index. The World Health Organization WHO (2011) standard for drinking purposes had been considered for calculation of WQI. In Iraq and other countries, many researchers studied the quality of groundwater for different purposes. Mahmood et al. (2013) used water quality index to evaluate the groundwater in Basrah city for drinking and irrigation. Al-Mohammed and Mutasher (2013) applied water quality index to evaluate groundwater quality for drinking purpose in Kerbala city. Ahmed (2014) assessed the suitability of groundwater quality for drinking purpose for some villages around Darbandikhan district, Kurdistan region, using water quality index. Ibrahiem (2015) applied WQI for a selected area of dibdibba aquifer southern of Iraq and represented the result as GIS maps to show the location of polluted areas.

2. STUDY AREA LOCATION

Basrah governorate is located in the southeastern part of Iraq. It overlooks the Gulf Arab head in the northern part. It is located between the longitudes of 47° 40' and 48° 30' of east and latitudes of 29° 50' and 31° 20' in the north. The estimated study area is19,070 km^2 which is equivalent to 762,800 acres as shown in Fig. 1. The study area is located within semi-arid zone. The prevailing climate in the study area is hot in Summer with a little rainfall in Winter. Study area located within earth formation named "Dibdibba formation", which has a large extension over a large area in the southern part of Iraq plus some area in the middle west of Iraq. Dibdibba formation age is upper Miocene- Pliocene, and it is consisting of sand, gravel with pebbles of igneous rocks and white quarts somewhere cemented into a hard grit (Jassim and Coff., 2006). It Dibdibba formation characterized by unconfined to semi-confined condition; the average of its saturated thickness is about (14m) (Al-Basrawi, 2006). The depth of selected wells varied from (15-25) m which have been chosen according to its availability in area.

3. METHODOLOGY

3.1. Groundwater samples collection

Water samples were collected from (29) wells distributed over different districts in the governorate (Safwan, Zubair, and Un-Qasr) during two periods. The first period was at the end of August (2015) through which sampling was from the wells belong to the General Authority for groundwater - Basrah branch, which is encoded by (W). While the second period was at the beginning of September (2015) through which sampling from the wells belongs to Basrah Environment Directorate, which is encoded by (E). Fig. 2 shows the location of wells in the study area. The analysis of samples was done in the laboratories of Basrah environment directorate-division of environmental analysis. The groundwater samples are collected after (10) minutes of pumping to avoid unpredictable change in characteristics of groundwater according to standard procedures (APHA, 1995). The time of sampling was in the morning by using polyethylene bottles of one litter volume (Rainwater and Thatcher, 1960), and the samples were transported to the laboratory within the same day of collection. pH, electrical conductivity (EC), total dissolved solid (TDS), and temperature (T˚) were measured immediately by using portable electronic instrument model SD300. Sodium and potassium were measured by flame photometer, Calcium, Magnesium, and total hardness were measured by Titration with EDTA (Ethylene DiamineTetrscitic Acid), chloride was measured by titration with $AgNO_3$, and sulphate measured by turbidity metric method. Bicarbonate was measured by technicon in volumetric procedure. While the phosphate was measured by Ascorbic acid method. Table (1) shows the maximum, minimum, and average values of the chemical parameters tested for the groundwater of the study area.

Fig. 1. Location of Basrah Governorate.

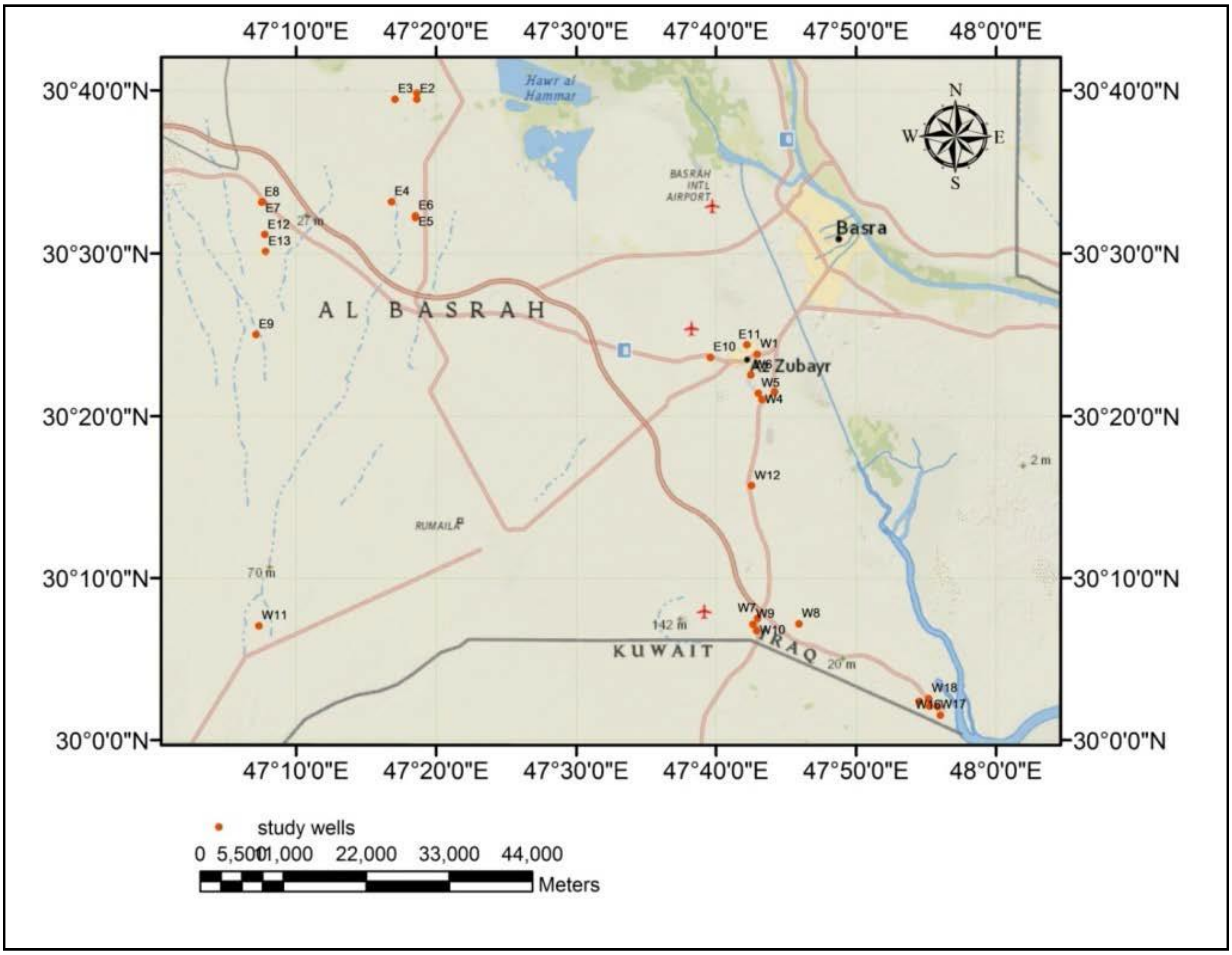

Fig. 2. Location of groundwater wells of the study area.

Table 1. Minimum, Maximum, and average value of physical and chemical parameters of groundwater samples

Parameter	Minimum	Maximum	Mean value
pH	6.6000	7.7000	7.2000
EC	4365.0	15750	8328.0
TDS	2182.0	13000	5167.5
TH(as CaCO3)	1360.6	5535.4	2259.1
Cl	380.00	4750.0	2185.4
HCO3	1215.0	4792.0	2163.2
SO4	700.00	4500.0	1317.2
NO3	8.7500	53.790	27.500
Ca	359.00	1280.0	576.50
Mg	75.000	579.00	200.20
Na	320.00	4500.0	1814.8
K	22.000	66.000	36.100
PO4	0.0800	2.6800	0.3600

3.2. Drinking water parameters

Eleven water parameters were determined and compared with the Iraqi standards (2009) and WHO standards (2011) as shown in Table (2).

Table 2. Water quality standards

Parameters	Iraqi standards (IQS) 2009	WHO Standards, 2011
pH	6.5-8.5	6.5-8.5
EC (µS/cm)	1500	1500
TDS (mg/l)	1000	1000
T.H as $CaCO_3$ (mg/l)	500	500
Ca^{+2} (mg/l)	50-150	75-200
Mg^{+2} (mg/l)	50-100	30-150
Na^{+} (mg/l)	200	200-400
K^{+} (mg/l)	N/A	12
SO_4 (mg/l)	250-400	200-400
Cl^{-} (mg/l)	250-350	200-600
NO_3^{-} (mg/l)	50	10-45
PO_4^{-} (mg/l)	N/A	5

3.3. Water quality index

Water Quality Index (WQI) considered the most effective tool to convey the water quality information in the simplest form to the public (Babaei, 2011). WQI transforms large and complex information of raw water quality data into a simplified and logical form with different categories of water quality that reflects the overall water quality status. Water quality index was calculated depending on eleven parameters. The WQI has been determined by using the drinking water quality standard recommended by World Health Organization (WHO, 2011).

To calculate WQI, the following steps were used:

1. First step : Each of 11 parameters (EC, PH, TDS, Cl, HCO_3, SO_4, NO_3, Ca, Mg, Na, and K) had been given an assigned weight (wi) according to their relative importance in the overall quality of water for drinking purposes as shown in Table (3) ranging from (1) to (5). A maximum weight of (5) is given to the parameters SO_4, NO_3, Cl, and TDS for their importance in water quality assessment, while a minimum weight value of (1) is given to the parameter K that plays an insignificant role in the water quality assessment (Channo, 2012).
2. Second step: finding the relative weight depending on the following equation (Ketata-Rokbani et al., 2011):

$$Wi = wi / \sum_{i=1}^{n} wi \tag{1}$$

Where: Wi = Relative weight

wi= Weight of each parameter

n= Number of parameters

3. Third step : calculating the quality rating Qi using the following equation:

$$\mathrm{Qi} = \left(\frac{\mathrm{ci}}{\mathrm{si}}\right) * 100 \tag{2}$$

Where: ci= Concentration of each parameter

si= Standard value of each parameters

4. The last step : is computing WQI using the following equations (Channo, 2012)

$$WQI = \sum_{i=1}^{n} (Wi * Qi) \quad (3)$$

Where: WQI= water quality index

Qi= rating based on the concentration of i^{th} parameter

Wi = relative weight of i^{th} parameter.

In the end of the last step, WQI is computed for each sample (each well). The water quality ratings on the basis of an index value for this WQI are summarized in Table (4). Fig. 3 shows the spatial distribution of water quality index in the study area.

Table 3. Water quality standards (WHO, 2011), assigned and relative weight value needed to calculate water quality index (WQI)

Parameters	Drinking Standard WHO 2011	Assigned Weight wi	Relative Weight Wi
PH	8.5	2	0.054
EC (mmohs/cm)	1500	3	0.081
TDS (mg/l)	500-1000	5	0.135
T.H as $CaCO_3$ (mg/l)	500	1	0.027
Ca^{+2} (mg/l)	75-200	3	0.081
Mg^{+2} (mg/l)	30-150	3	0.081
Na^{+} (mg/l)	200-400	4	0.108
K^{+} (mg/l)	12	1	0.027
SO_4 (mg/l)	200-400	5	0.135
Cl^{-} (mg/l)	200-600	5	0.135
NO_3^{-} (mg/l)	10-45	5	0.135
		$\sum = 37$	$0.999 \approx 1$

Table 4. WQI range and type of water classification

Range	Type of water
< 50	Excellent water
50-100	Good water
100.1-200	Poor water
200.1-300	Very poor water
>300	Water unsuitable for drinking purposes

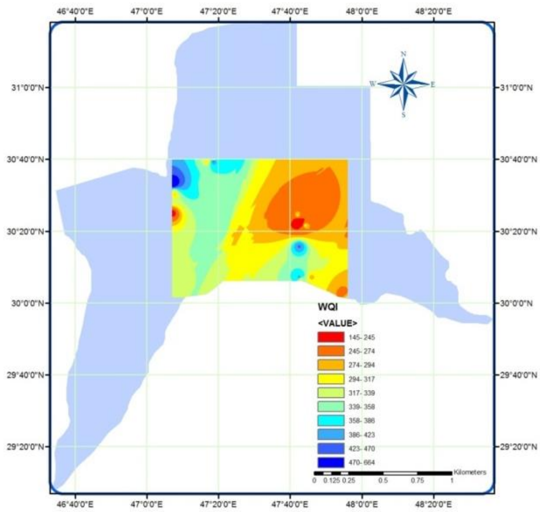

Fig. 3. Spatial Distribution of Water Quality Index in study area.

4. RESULTS AND DISCUSSION

4.1. pH

pH is one of the most important water quality parameters. The maximum permissible limit for pH in drinking water as given by WHO is 8.5 while its minimum is 6.5. The pH values of the samples tested vary from 6.6 to 7.7 with a mean value of 7.7 (Table 1). This shows that the quality of groundwater of the study area is within the desirable limit. The variations in pH values may be due to the chemical composition of the Dibbdiba aquifers in the study area. Fig. 4 shows the spatial distribution of pH in the study area.

4.2. Total dissolved solid (TDS)

The concentration of dissolved solids in groundwater is important to decide its suitability for drinking, irrigation, or industrial purposes. Groundwater containing more than 1000 mg/l of the total dissolved solids is generally referred as brackish water. The TDS concentration of the samples in the study area ranged from 2182 to 13000 ppm with a mean value of (5,167.5) ppm. All water samples in the study area are fallen under higher solids content. Fig. 5 shows the spatial distribution of TDS in the study area.

4.3. Electrical conductivity (EC)

Electrical conductivity is an indirect measurement of salinity, and it is temperature dependent where an increase in water temperature of one degree Celsius cause an increase in electrical conductivity by (2%) (Hem, 1985). The values of EC concentration of the samples in the study area were ranged between (4,365-15,750) µS/cm with a mean value of (8328) µS/cm. All water samples in the study area are lies above the maximum permissible limit for drinking water purposes. Fig. 6 illustrates the spatial distribution of EC in the study area.

4.4. Sodium (Na^+)

The major source of sodium content in the groundwater is due to the presence of salts. Desirable limit of sodium content in groundwater is (200-400) mg/l. The maximum concentration of sodium in the samples of the study area was (4,500) ppm, and the minimum was (320) ppm with a mean value of (1,814.8) ppm. Concentration excess of (200) ppm of sodium considered as unacceptable (salty) taste (Schmoll et al., 2006). Fig. 7 shows the spatial distribution of Na in the study area.

4.5. Calcium (Ca^{2+})

The concentration of calcium ion in the study area was ranged between (359-1,280) ppm with a mean value of (576.5) ppm. The permissible limit of calcium is (75-200) mg/l. The increase in calcium concentration may be due to the type of water carrying strata which have calcite, dolomite, gypsum, and anhydrate minerals that have the direct effect on enriching the groundwater in the study area with calcium ions (Al-Mansory, 2000). Fig. 8 shows the spatial distribution of Ca in the study area.

4.6. Magnesium (Mg^{2+})

Magnesium occurs in water mainly due to the presence of Olivine, Biotite, Augite, and Talc minerals. The results showed that the magnesium of groundwater in the study area was ranged from (579) ppm to (75) ppm with a mean value of (200.2) ppm. The permissible limit of magnesium is (30-150) mg/l. The presence of Dolomite rocks in Dibdibaa quifer, which is the local sources of Magnesium, may result in high values of magnesium ion concentration in the study area (Haddad, 1977). Fig. 9 shows the spatial distribution of Mg in the study area.

4.7. Potassium (K^{+})

Potassium is an essential for plants and animals. Potassium salt in most rock was not easily dissolved in groundwater (Stumm and Morgan, 1996). The maximum concentration of potassium in the samples of the study area was (66) ppm and, the minimum concentration was (22) ppm with a mean value of (36.1) ppm. Fig. 10 shows the spatial distribution of K in the study area.

4.8. Chloride (Cl)

Chloride is present in all natural waters at greatly varying concentration depending on the geochemical conditions. The maximum value of Cl in the samples of the study area was (4,750) ppm, and the minimum value was (380) ppm with a mean value of (2,185.4) ppm. When chloride concentration exceeds 600 mg/l, it gives water detectable or salty taste, which is objectable to many people (WHO, 2011). Fig. 11 shows the spatial distribution of Cl in the study area.

4.9. Sulfate (SO_4^{2-})

Sulphates occur in natural water at a concentration up to 50 mg/l. The presence of high concentration sulfate in drinking water causes noticeable taste and might contribute to the corrosion of distribution pipe network system (WHO, 2011). The recommended upper limit is 400 mg/l in water intended for human consumption. Sulfate concentration ranges from (4,500) ppm to (700) ppm with a mean value of (1,317.2) ppm in the samples of the study area. The high concentration of sulfate in groundwater of the study area may be due to existance of Miocene sediments containing gypsum and limestone (Qusay and Al-Mansory, 2003). Fig. 12 shows the spatial distribution of sulphate in the study area.

4.10. Bicarbonate (HCO^{3-})

Dissolution of carbonate rocks usually causes a high concentration of bicarbonate (Hem, 1991). Bicarbonate is expressed in mg/l as $CaCO_3$. The maximum concentration of bicarbonate in the study area was (4,792) ppm, and the minimum concentration was (1,215) ppm with a mean value of (2,163.2) ppm. Fig. 13 shows the spatial distribution of HCO^{3-} in the study area.

4.11. Nitrate (NO_3)

The excessive concentration of nitrate in groundwater becomes toxic to human when exceeds 45 ppm. The maximum concentration of nitrate was (53.79) ppm, and the minimum was (8.75) ppm with a mean value of (27.5) ppm in the samples of the study area. Fig. 14 shows the spatial distribution of NO_3 in the study area.

4.12. Phosphate (PO_4^{3-})

It is an essential element for plant life, but when there is too much more than 5 ppm of it in water, it can speed up eutrophication of rivers and lakes. The maximum concentration of phosphate in the study area was (2.68) ppm, and the minimum concentration was (0.08) ppm with a mean value of (0.36) ppm. Fig. 15 shows the spatial distribution of PO_4^{3-} in the study area.

The results of groundwater classification for (29) wells in the study area by using WQI method are shown in Table (5) and Fig. 16. Water quality index (WQI) varied from poor class to unsuitable class for drinking purpose.

Table 5. WQI range and type of water classification in the study area

Sample	WQI	Type of water	Sample	WQI	Type of water
W1	248.3	Very poor	W16	243.43	Very poor
W2	308.39	Unsuitable	E1	304.98	Unsuitable
W3	271.53	Very poor	E2	452.99	Unsuitable
W4	209.03	Very poor	E3	301.21	Unsuitable
W5	144.97	Poor	E4	339.55	Unsuitable
W6	373.41	Unsuitable	E5	341.58	Unsuitable
W7	285.93	Very poor	E6	365.29	Unsuitable
W8	426.02	Unsuitable	E7	321.50	Unsuitable
W9	298.17	Very poor	E8	754.33	Unsuitable
W10	327.93	Unsuitable	E9	231.28	Very poor
W11	428.67	Unsuitable	E10	258.52	Very poor
W12	267.05	Very poor	E11	303.33	Unsuitable
W13	278.00	Very poor	E12	314.16	Unsuitable
W14	307.12	Unsuitable	E13	291.58	Very poor
W15	294.36	Very poor	N/A	N/A	N/A

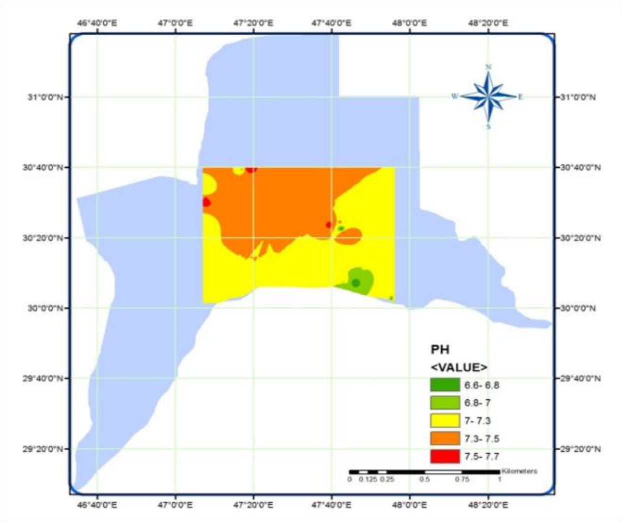

Fig. 4. Spatial distribution of pH in the study area.

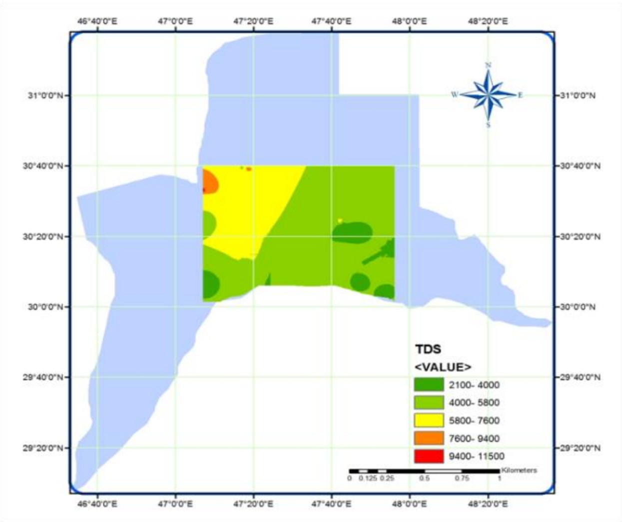

Fig. 5. Spatial distribution of TDS in study area.

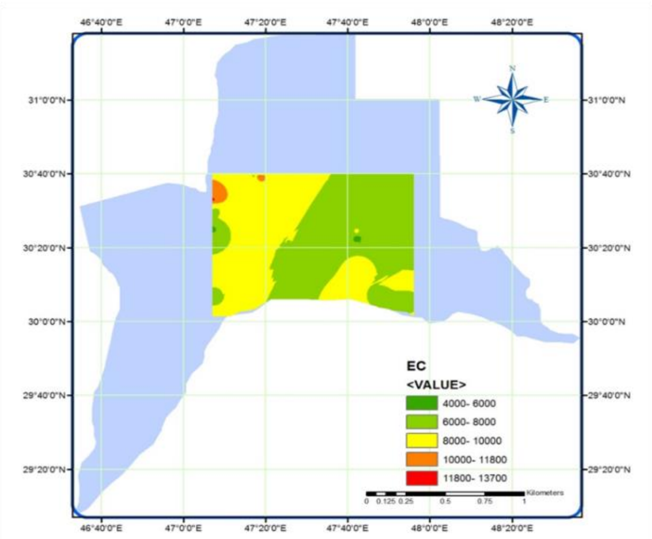

Fig. 6. Spatial distribution of EC in study area.

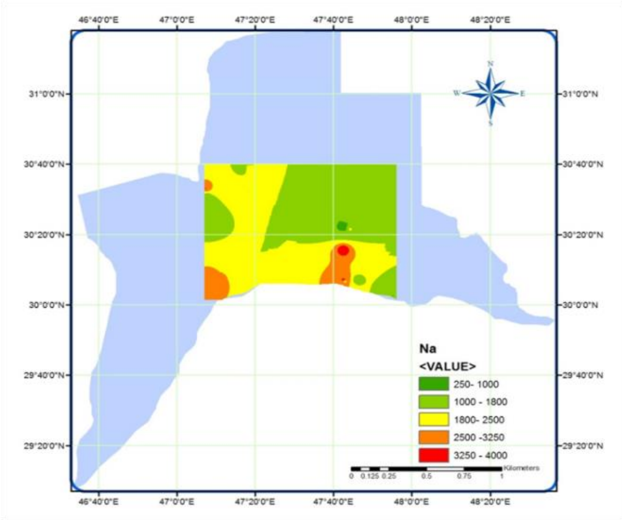

Fig. 7. Spatial distribution of Na in the study area.

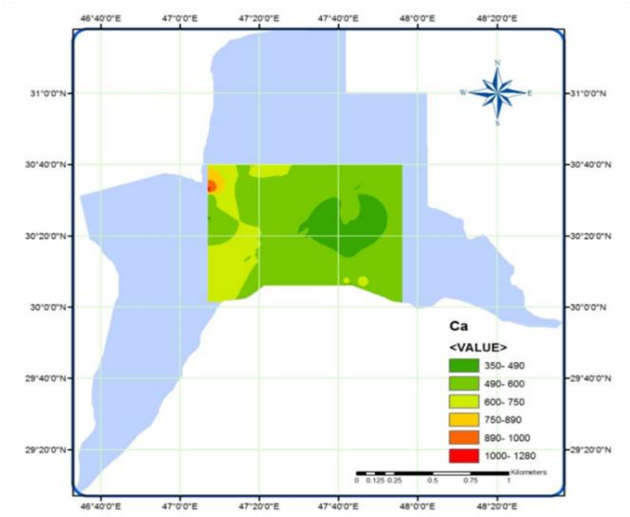

Fig. 8. Spatial distribution of Ca in study area.

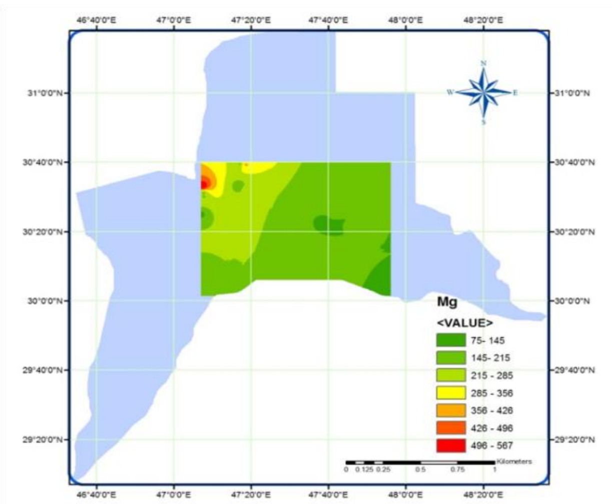

Fig. 9. Spatial distribution of Mg in study area.

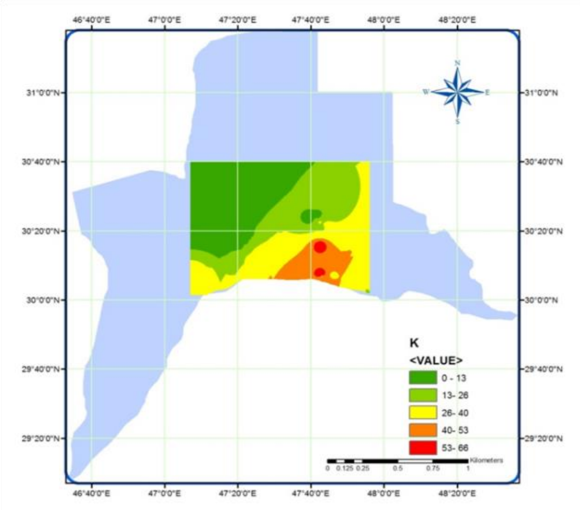

Fig. 10. Spatial distribution of K in the study area.

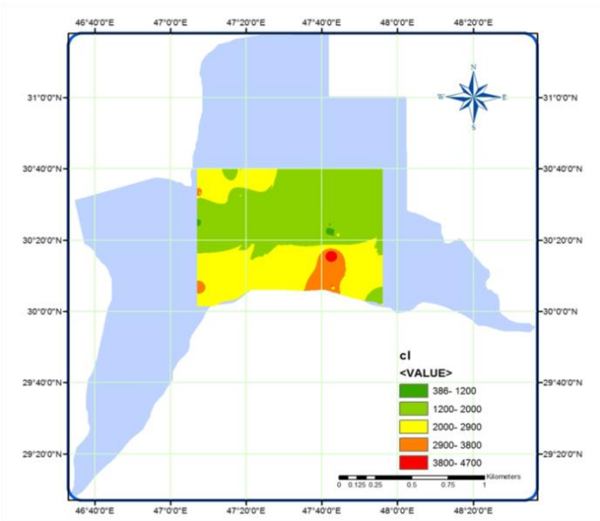

Fig. 11. Spatial distribution of Cl in the study area.

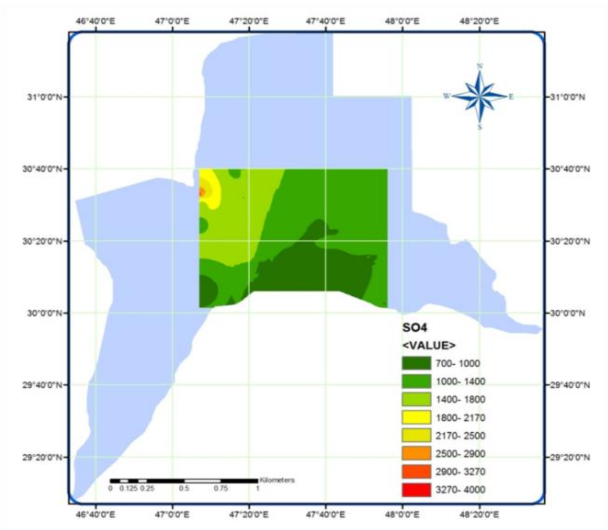

Fig. 12. Spatial distribution of SO4 in the study area.

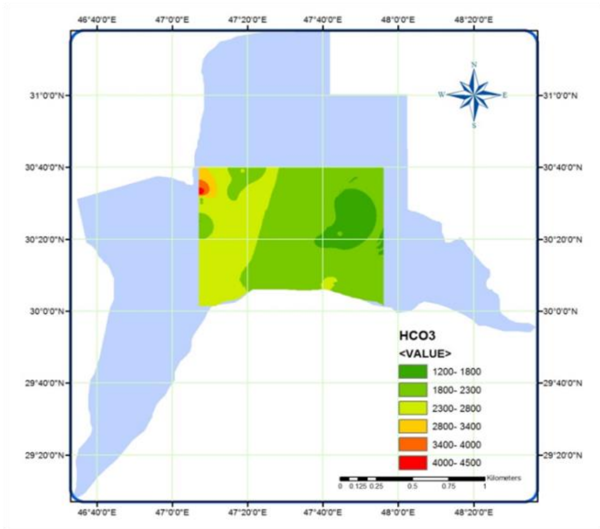

Fig. 13. Spatial distribution of HCO3 in the study area.

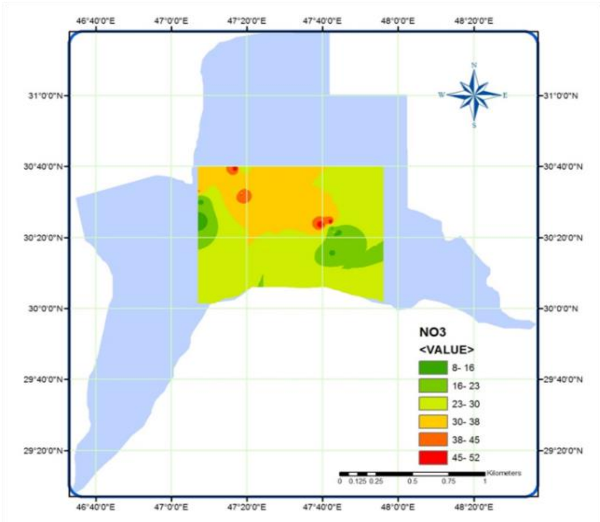

Fig. 14. Spatial distribution of NO_3 in the study area.

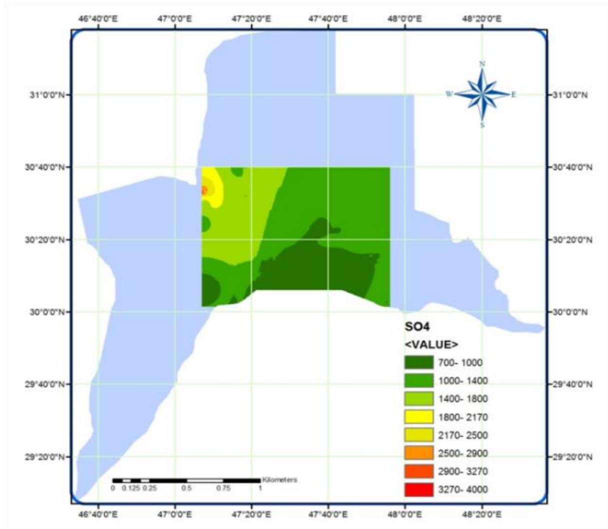

Fig. 15. Spatial distribution of PO_4 in the study area.

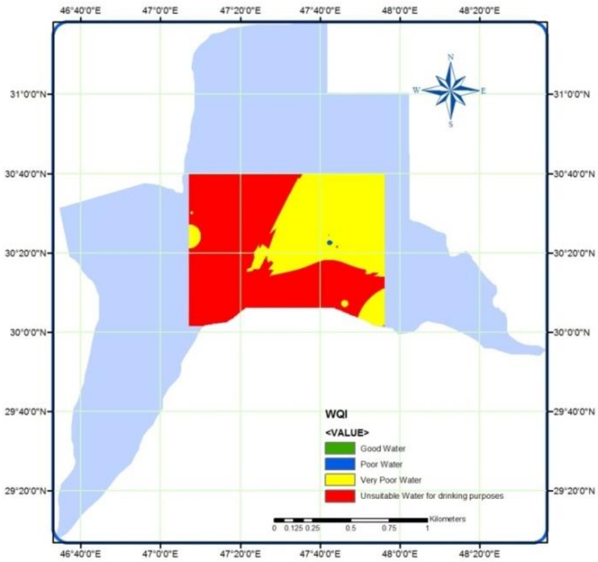

Fig. 16. WQI classification for groundwater of study area.

5. CONCLUSIONS

Generally, the concentration of salts and major ions in groundwater of the study area are high. Most of the water parameters are above the permissible limits of standards of WHO and IQS.

The overall view of the WQI (Table 5) of the present study shows a higher WQI, which exceeds the limitation of standards. The results of the study confirm the unsuitability of all samples in the study area for human drinking purpose.

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