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Spatial Distribution of Groundwater Quality Index in Safwan-Zubair Area

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Abstract: Safwan-Zubair area is located in southwest of Basrah Province, South of Iraq. This area is located between longitude line [47°35’-47°55’] and latitude line [30°00’-30°30’]. The main source for irrigation and domestic purposes in the study area is groundwater. The upper aquifer of Dibdibba formation represents the main aquifer in Safwan-Zubair area. The main object of this research is to evaluate the water quality for drinking and agricultural purposes through physical and chemical analysis (Temperature, pH, EC, TDS, Cl^-, Na^+, K^+, Ca^{+2}, Mg^{+2}, HCO_3^-, SO_4^{-2}, Fe^+, Total Alkalinity (TA), Total Hardness (TH)) using Groundwater Quality Index (GWQI), Sodium Adsorption Ratio (SAR) and percentage of sodium ion (Na%) during the wet season (2018). Based on SAR values, the groundwater types ranged from first class (excellent) to the second class (good). Na% values ranged from 37.29-60.54%, according to this range, it is found that the groundwater type ranged from good to doubtful class. According to GWQI, the groundwater quality lies under unsuitable class. The general trend of directional distribution of Na^+ concentration is from the northwest to the southeast in other words with align of the Shatt Al-Basrah Canal (drainage canal), there is a clear effect of the canal on the adjacent areas lead to increase the concentration of Na^+. The groundwater flow direction has a great effect on the quality of groundwater along with the direction of groundwater path lines towards the Arabian Gulf near Um Qasr.

Key words: Safwan-Zubair area, groundwater quality index, sodium adsorption ratio, GIS, natural neighbor method, Iraq

INTRODUCTION

Study of water resources quantity and its quality is a basic necessity in recent times where it’s considered as economic and vital resources. Based on the basic quality, water is used in various sectors sense, agriculture, energy and industry. Therefore, a person should be interested in collecting basic information on the quality and quantity of water resources for its suitable usage and management. The increasing demand of water due to population growth and development of industrial and agricultural activities has led to increase the usage of groundwater compared with surface water sources, resulting in the depletion of groundwater. Groundwater quality is usually characterized by different physical-chemical properties. These parameters vary widely because of different types of pollution, seasonal fluctuations, groundwater extraction and so forth. Groundwater monitoring is therefore mandatory in order to reduce groundwater pollution and control pollution factors (Deshmukh and Aher, 2016).

Water Quality Index (WQI) is beneficial for discovering the appropriateness of water for a variety of usages such as irrigation and domestic use. It is used to bind a set of physical and chemical parameters on a scale and merge them into a single number (Yisa and Jimoh, 2010; Lescesen *et al*., 2015). WQI is determine the general state of water quality at a given time and place. WQI was invented by Brown *et al.* (1970) and progress by Deininger for the Scottish Development Department. Groundwater Water Quality Index (GWQI) was developed in the previous literature by various researchers. Backman *et al.* (1998) provided an indicator for assessing and studying the degree of groundwater pollution and its applicability in south-west Finland and Central Slovakia. Nives (1999) presented the WQI both for surface waters and groundwater and its application for water assessment in Dalmatia, Croatia. Soltan (1999) provided WQI to study the groundwater quality by 10 wells located near the Dakhla Oasis in Egypt. Various studies such as Stigter *et al*. (2006a, b), Babiker *et al*. (2007), Rivard *et al*. (2008) and Kim (2009) have been conducted on a regional scale in relation to the quality and quantity of groundwater. Ishaku *et al.* (2012) presented study for assessment ground water quality using water quality index and GIS in Jada, north eastern Nigeria. (Kumari and Rani, 2014) have been presented study for determining of GWQI and correlation analysis of groundwater of Smalkhan Tehsil, Panipat District, Haryana India. The results of this study reveal that highly industrial zone and

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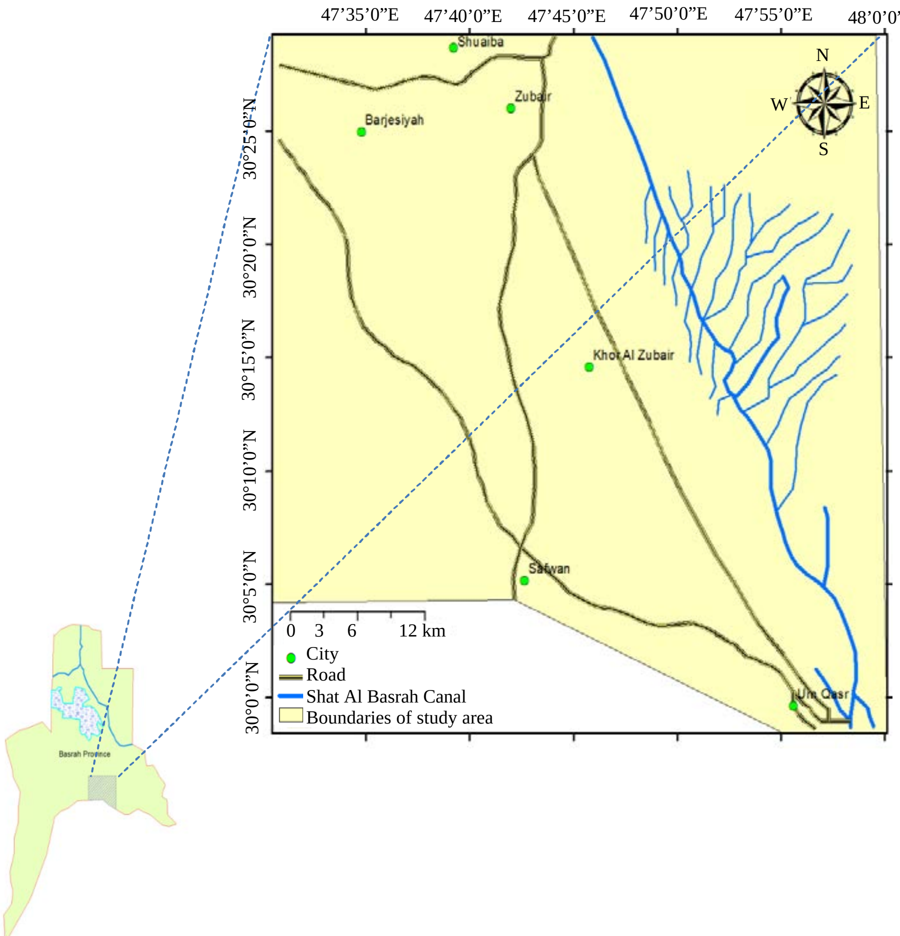

Fig. 1: Location of study area in reference to the map of Basrah Province

anthropogenic activities lead to pollution of natural resources. The Averaged Water Quality Index (AWQI) was used by Shahid and Iqbal (2016) the study evaluated the groundwater physicochemical parameters (turbidity, pH, total dissolved solids, hardness, chlorides, alkalinity and calcium) for three years. The methodology of this research could be adopted in other mega cities as well to monitor groundwater quality.

The aim of this research is to evaluate the water quality for drinking and agricultural purposes at Safwan-Zubair area, Southwest of Basrah Province, through physical and chemical analysis using GWQI during the wet season (2018). The Sodium Adsorption Ratio (SAR) and Na^{+}% are calculated in for investigating the suitability of studied groundwater for irrigation purposes.

Description of the study area: Safwan-Zubair area is located in Southwest of Basrah Province, Southern Iraq. This area is located between longitude line [47°35’-47°55’] and latitude line [30°00’-30°30’] the studies area is about 2009 km^2 as shown in Fig. 1. Rainfall usually starts through October till May. During the summer season, air temperature rises up to above 45°C, so, Basrah Province is one of the hottest cities on the planet (Al-Aboodi 2016). This area constitutes the southern part of the Iraqi desert, an arid region with scarce and limited resources. There is no surface water in the area and the only drainage canal is the Shat Al-Basrah Canal, groundwater is a major natural resource in this area. Groundwater is used in Safwan-Zubair area for industrial and agricultural purposes where this area is considered to be the most important areas of Basrah Province, many farms and factories are spread in this area. The upper part of Dibdibba formation represents the most important aquifer in the study area which is mainly composed of sand and gravel with some cementing materials such as silt and clay.

MATERIALS AND METHODS

Six sites were selected to collect groundwater samples in Safwan-Zubair area (Zubair, Safwan, Shuaiba, Barjesiyah, Khor Al Zubair and Um Qasr) during the wet season (2018) as shown in Fig. 1. Groundwater sample is collected by plastic bottle where it is fully filled and placed in a refrigerated box until it is transferred to the laboratory. Transparent and dark winkler bottles of 250-300 mL are used to collect water samples with avoiding any air bubbles. Each container is marked with a name and date of sampling. The locations of the different water samples were determined using GPS. Field parameters such as temperature, pH, EC and TDS were determined in the field using digital conductivity meter, temperature (digital thermometer), HANNA pH meter (Model HI 28129) for determining pH (HM digital EC/TDS Hydrotester COM-80) for EC and TDS. All chemical analysis was carried out according to the standard method by APHA and guide manual: water and waste water analysis (CPCB). The methodologies adopted for determination of physicochemical parameters of the collected samples as shown in Table 1.

The overall water quality data of Safwan-Zubair were compared with the World Health Organization (WHO) guidelines for drinking water (2011) as well as the aquatic life standards adopted by CCME as shown

Table 1: Water quality parameters and their associated units and analytical method used

Variables/units	Analytical method
Temperature (°C)	Digital thermometer
pH unit	pH meter
EC (µS/cm)	Electrometric
TDS (mg/L)	Electrometric
Cl^- (mg/L)	Titrimetric
Na^+ (mg/L)	Flame photometer
K^+ (mg/L)	Flame photometer
Ca^{+2} (mg/L)	Titrimetric
Mg^{+2} (mg/L)	Titrimetric
HCO_3^- (mg/L)	Spectrophotometric
SO_4^{-2} (mg/L)	Spectrophotometric
Fe^+ (mg/L)	Spectrophotometric
TA (mg/L)	Titrimetric
TH (mg/L)	Titrimetric
PO_4^-(mg/L)	Spectrophotometric

in Table 2. It is important to determine the concentration of sodium in irrigation water when using this water for irrigation purposes; It has a direct influence on soil structure and plant growth. There are two parameters that give a clear indication of sodium concentration and its effect on soil structure and plant growth (Sodium Adsorption Ratio "SAR" and Na%) SAR is calculated as follows (cations expressed as meq/L:

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

Most of the specifications for the suitability of water for irrigation purposes confirmed that the ratio of Na^+ should not exceed 60 in order to avoid its deleterious influence on soil. Percentage of Na^+ can be determined using the following formula (Cations expressed as meq/L):

$$Na\% = \frac{Na}{Ca+Mg+K+Na} \times 100 \quad (2)$$

GWQI is the most efficient ways to provide information on water quality to consumers and decision-makers. By this method, the user has a clear perception for the quality of groundwater and for various uses, also; the combined effect of water quality parameters can be summed in single quality index called WQI (Sahu and Sikdar, 2008). Thirteen physical and chemical parameters (pH, TDS, EC, K, Ca, Mg, Cl, Na, Fe, HCO_3, SO_4, TA nad TH) were selected according to their importance in water quality as illustrated in Table 3. GWQI is calculated in the study area by following steps:

According to the effect of each chemical parameter on the health and quality of drinking water is determined its weight (wi) as shown in Table 3. The top weight was

Table 2: Water quality parameters values of groundwater in the study area and comparative guidelines

	DS (mean±SD)							
Variables	Zubair	Safwan	Shuaiba	Barjesiyah	Um Qasr	Khor Al-Zubair	Drinking water WHO (2011)	Aquatic life CCME (2007)
Temperature	19±1.2	19±1.4	18±1.6	19±1.9	18±1.3	18±1.5	-	-
pH	7.8±0.35	7.87±0.37	8.0±0.39	7.78±0.28	8±0.33	8.1±0.30	6.5-8.5	6.5-9
EC (µS/cm)	6180±74.2	16620±104.2	14200±97.5	9160±63.5	11360±76.1	8770±55.9	-	-
TDS (mg/L)	4079±43.4	10969±76.5	9372±61.5	6046±34.5	7498±45.7	5788±43.2	1000	
Cl^- (mg/L)	1228.8±23.2	1100±19.5	1372.2±5.4	1343.4±24.2	1956.8±28.6	1328.7±27.6	250	120*
Na^+ (mg/L)	905±86.3	1103±59.3	860±54.3	832±41.5	956±47.3	928±40.3	200	
K^+ (mg/L)	32.5±2.1	52±4.3	36±2.7	33±2.3	40±3.8	39±3.6	-	-
Ca^{+2} (mg/L)	364±20.4	266±29.5	228±21.5	397±23.4	553±17.4	213±21.3	-	-
Mg^{+2} (mg/L)	234±9.0	760±12.4	614±12.4	267±10.2	131±6.6	178±8.0	-	-
HCO_3^- (mg/L)	146±29.4	124±18.9	127±26.5	63±14.3	81±13.8	168±20.9	-	-
SO_4^{-2} (mg/L)	2402±34.2	2445±36.7	2359±12.5	2288±38.2	3459±35.8	3046±37.3	500	-
Fe^+ (mg/L)	0.06±0.001	0.074±0.0012	0.172±0.001	0.09±0.001	0.01±0.0008	0.014±0.001	-	-
TA (mg/L)	146±17.2	124±15.8	127±13.4	63±8.6	81±11.3	168±18.6	-	-
TH (mg/L)	598±34.7	1026±39.7	842±29.3	664±26.5	684±27.8	611±26.0	500	-

*Significant values

Table 3: Weight and relative weight of physical and chemical parameters (Ravikumar *et al*. 2013)

Parameters	BIS., desirable limit (Sibson, 1981)	Weight (W_i)	Relative weight (W_i)
pH	8.5	3	0.0857
EC (µS/cm)	2000	3	0.0857
TDS (mg/L)	1000	5	0.1429
Cl^- (mg/L)	250	3	0.0857
Na^+ (mg/L)	100	3	0.0857
K^+ (mg/L)	10	2	0.0571
Ca^{+2} (mg/L)	75	2	0.0571
Mg^{+2} (mg/L)	30	2	0.0571
HCO_3^- (mg/L)	200	2	0.0571
SO_4^{-2} (mg/L)	200	3	0.0857
Fe^+ (mg/L)	0.3	2	0.0571
TA (mg/L)	200	2	0.0571
TH (mg/L)	300	3	0.0857
	-	$\Sigma W_i = 35$	$\Sigma W_i = 1$

set to 5 for parameters have significant effects on water quality such as (TDS). The low weight of the chemical parameter indicates its small effect on water quality such as (Mg, Ca, K and TA). The relative Weight (Wi) is calculated by using Eq. 3. The (qi) is determined by using Eq. 4, through dividing the concentration of each parameter on its standard value based on the guidelines laid down by BIS (Sibon). Sii (the quality sub-index for the parameter) is determined by multiplying the relative weight of the parameter by its (qi) using Eq. 5. GWQI is determined by summing all over quality sub-index for each parameter using Eq. 3:

$$W_i = \frac{w_i}{\sum_{n=1}^{n} w_i} \quad (3)$$

Where:

W_i = Relative weight
w_i = Chemical parameter weight
n = Parameter number

$$q_i = \left(\frac{v_n - v_i}{v_s - v_t}\right)100 \quad (4)$$

Where:

q_i = Quality rating
V_n = Actual value of nth parameter
V_i = Parameter ideal value ($V_i = 0$, except for pH ($V_i = 7$)
V_s = Indian drinking water standard (BIS., 1998)

$$SI_i = W_i q_i \quad (5)$$

where, Si_i, sub-index of ith parameter:

$$WQI = \sum_{i=1}^{n} SI_i \quad (6)$$

GPS was used to specify the location of point sampling site and the results of (GWQI, SAR and Na%) were inserted in GIS environment for further analysis. The map showing spatial distribution of quality parameters was scanned and imported into Arc GIS Version 10.3, the scanned map with other geographical data need to be referenced. This means that every pixel in the scanned image gets a new dimension. The different locations of the sampling points were imported into GIS software through point layer for creating a vector point layer using coordinates data stored in an excel sheet. The geo-database was used to generate the spatial distribution maps of (GWQI, SAR and Na%). The natural neighbor method which developed by Sibson (1981) is used for spatial interpolation of (GWQI, SAR and Na%). Voronoi tessellation of a discrete set of spatial points is used in this method. It has features that go beyond simpler interpolation methods such as the closest interpolation in that it provides a smoother approximation of the "real" function. The basic interpolation equation in two dimensions as follows:

$$G(x, y) = \sum_{i=1}^{n} w_i f(x_i, y_i) \quad (7)$$

Where:

G (x, y) = The estimated function at (x_i, y_i)
w_i = The weights
F (x_i, y_i) = The known functions at (x_i, y_i)

The weights were calculated by determining the amount of "stolen" of each of the surrounding areas when inserting (x_i, y_i) into the tessellation. Directional distribution method (standard direction ellipse) is used in this research, this is a common way of measuring the direction of a set of points or regions, it's determined the standard distance separately in the x and y directions. These measurements determine elliptical axes that include the distribution of features. The ellipse axes are determined by calculating the standard deviation of the axes towards x and y direction from the mean center. This shape provides if the distribution of features is extended and then has a specific orientation. The standard deviations for the x-axis and y-axis are:

$$\sigma_x = \sqrt{\frac{\sum_{i=1}^{n}(\tilde{x}_i \cos\theta - \tilde{y}_i \sin\theta)^2}{n}}$$
$$\sigma_y = \sqrt{\frac{\sum_{i=1}^{n}(\tilde{x}_i \sin\theta - \tilde{y}_i \cos\theta)^2}{n}} \quad (8)$$

where, $\tilde{x}_i$ and $\tilde{y}_i$ are the deviations of the xy-coordinates from the mean center:

$$\tan\theta = \frac{A+B}{C} \quad (9)$$

$$A = \left(\sum_{i=1}^{n}\tilde{x}_i^{\,2} - \sum_{i=1}^{n}\tilde{y}_i^{\,2}\right)$$
$$B = \sqrt{\left(\sum_{i=1}^{n}\tilde{x}_i^{\,2} - \sum_{i=1}^{n}\tilde{y}_i^{\,2}\right)^2 + 4\left(\sum_{i=1}^{n}\tilde{x}_i\tilde{y}_i\right)^2} \quad (10)$$
$$C = 2\sum_{i=1}^{n}\tilde{x}_i\tilde{y}_i$$

RESULTS AND DISCUSSION

The chemical analyses of the groundwater in the study area were compared with WHO guidelines for drinking water (2011) in addition to aquatic life criteria endorsed by CCME. Normal statistics of water quality parameters of 60 groundwater samples distributed over the study area are presented in Table 2. The allowable value of pH in natural water is usually between 6.5 and 9 as described in the WHO (2011) in addition to the aquatic life standards approved by CCME. There is a close relationship between pH and water solubility as well as chemical form nad it has a direct effect on aquatic life activities. All studied samples placed in the acceptable range, the pH values range from 7.78-8.1.

TDS concentration is another expression that refers to ions in water. The value of TDS increases in water as the concentration of ions increases such as (Cl^-, Na^+, K^+, Ca^{+2}, Mg^{+2}, HCO_3^-, SO_4^{-2}). The study area had very high values of electrical conductivity and TDS. The concentration of TDS varied from 4079 mg/L in Zubair to 10969 mg/L in Safwan while the EC values ranged from 6180 (μS/cm) in Zubair area to 16620 (μS/cm) in Safwan area. There is a direct relationship between the TDS and EC in the study area. Very high TDS compared to standard limit of 1000 mg/L may be due to high concentrations of cations and anions.The maximum concentration of Cl^- measured 1956 mg/L in Um Qasr and minimum concentration is 1100 mg/L in Safwan. The main reason of its existence in such high concentration is the agricultural activity caused by the high manure of organic remaining or results from sea water invasion to the coastal areas (Todd, 1980) this reason is confirm with situation of Um Qasr area which it's coastal area. The concentration of sodium ranged from 832 mg/L in Barjesiyah to 1103 in Safwan. High concentrations of Na^+ are due to the deposition of the Dibdibba sandstone from the igneous rocks in the Arabian Shield which is transferred to a sedimentary basin containing a large amount of sodium (Sadik, 1977). The maximum and minimum value of K^+ is 52 mg/L, 32.5 mg/L in Safwan and Zubair, respectively, the low concentration of potassium in the study area is due to the high ability of soil glue to fix these ions. It also, indicates a weak access to groundwater when it's added as fertilizer (Spalding and Exner, 1980). The concentration of Ca^{+2} ranged from 213 mg/L in Khor Al Zubair to 553 mg/L in Um Qasr, the calcite and gypsum minerals areconsidered to be the main sources of this ion in Dibdibba formation. The maximum and minimum value of Mg^{+2} is 760 and 131 mg/L in Safwan and Um Qasr, respectively, the geochemical behavior of this ion is similar to calcium behavior (Davis and DeWiest, 1966). The concentration of HCO_3^- is varied from 63 mg/L in Barjesiyah to 168 mg/L in Khor Al Zubair, the high concentration of calcium and magnesium leads to the deposition of this ion. The maximum concentration of SO_4^{-2} in the study area is 2459 mg/L in Um Qasr and minimum concentration is 2288 mg/L in Barjesiyah, the presence of this ion with such high concentration is due to the presence of gypsum in a large amount in the Dibdibba formation. The concentration of Fe^+ was found to be low in different six sampling sites. Hardness in all sampling sites exceeded the permissible limit that endorsed by WHO (2011).

Table 4 which illustrated the suitability of water for serve irrigation purposes depending on SAR values. Table 5 is shown the SAR value in the study area, based on this classification, SAR values ranged from first class (excellent) to the second class (good). Figure 2 shows the distribution of SAR over the study area.

Na% values ranged from 37.29-60.54% as shown in Table 6, based on the comparison with Table 7, it is found that the type of groundwater ranged from good to doubtful class. Figure 3 shows the distribution of Na% over the study area.

According to the groundwater quality parameters, GWQI was determined for each sampling location as shown in Table 8. GWQI is categorized according to the scale adopted by Ramakrishnaiah *et al.* (2009) and Mohanty (2004) as illustrated in Table 9. The groundwater quality of studied area falls under unsuitable class (Fig. 4). Directional distribution method (standard direction ellipse) is used in this study. This shape provides if the

Table 4: Suggested limits of SAR for irrigation purposes (Ravikumar *et al.* 2013)

Grade	Excellent	Good	Fair	Poor
SAR	0-10	10-18	18-26	>26

Table 5: SAR values of Safwan-Zubair area during wet season

SAR Zubair	Safwan	Shuaiba	Barjesiyah	Um Qasr	Khor Al-Zubair
9.09	7.79	6.72	7.91	9.48	11.34

Table 6: Na% values of study area

Na%

Zubair	Safwan	Shuaiba	Barjesiyah	Um Qasr	Khor Al-Zubair
50.68	38.32	37.29	45.88	51.29	60.54

Table 7: Water class based on Na^+ percentage ratio (Wilcox 1995)

Class	Excellent	Good	Permissible	Doubtful	Unsuitable
Na%	<20	20-40	40-60	60-80	>80

Table 8: GWQI values of study area

GWQI Zubair	Safwan	Shuaiba	Barjesiyah	Um Qasr	Khor Al-Zubair
429.42	702.49	611.80	469.76	573.09	481.37

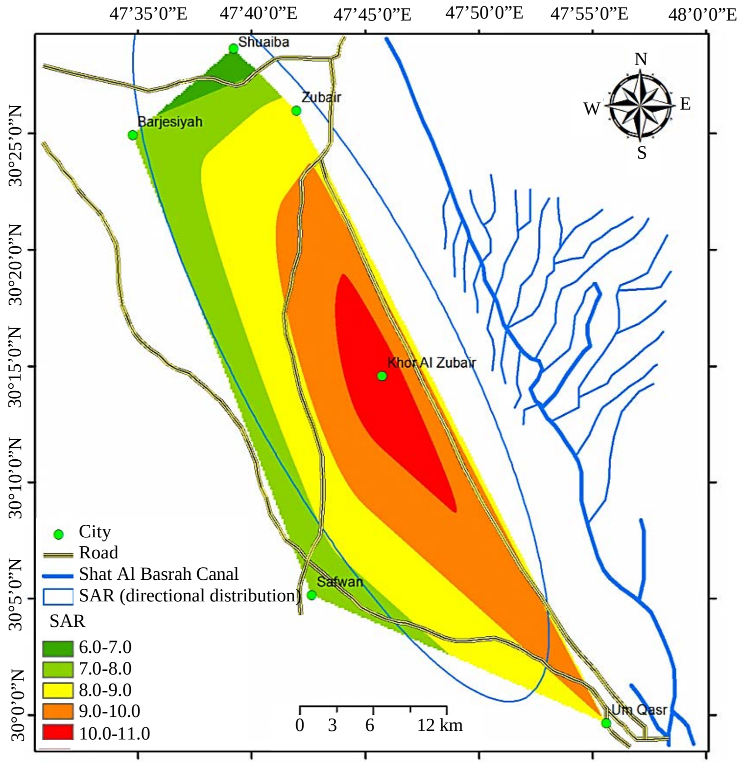

Fig. 2: Distribution of SAR over study area

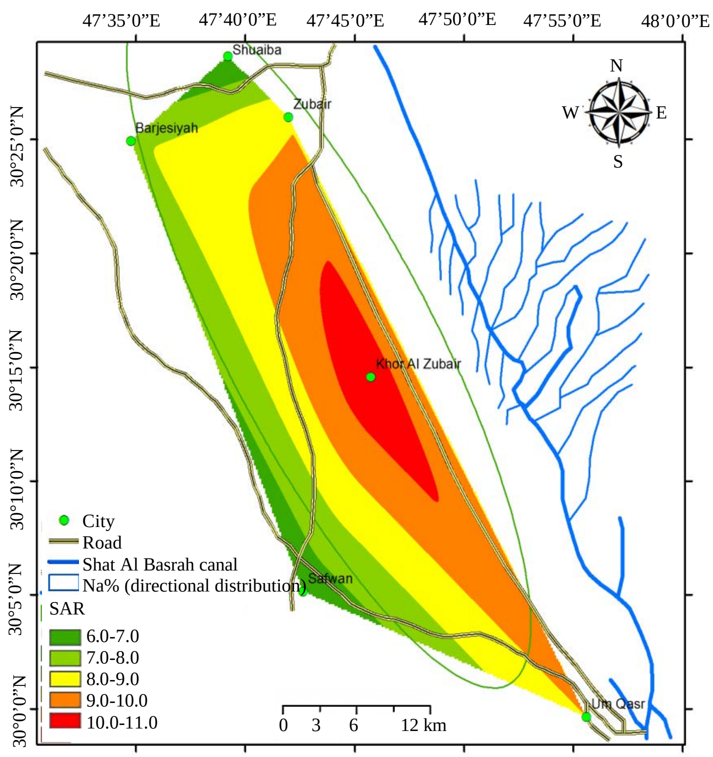

Fig. 3: Distribution of Na% over study area

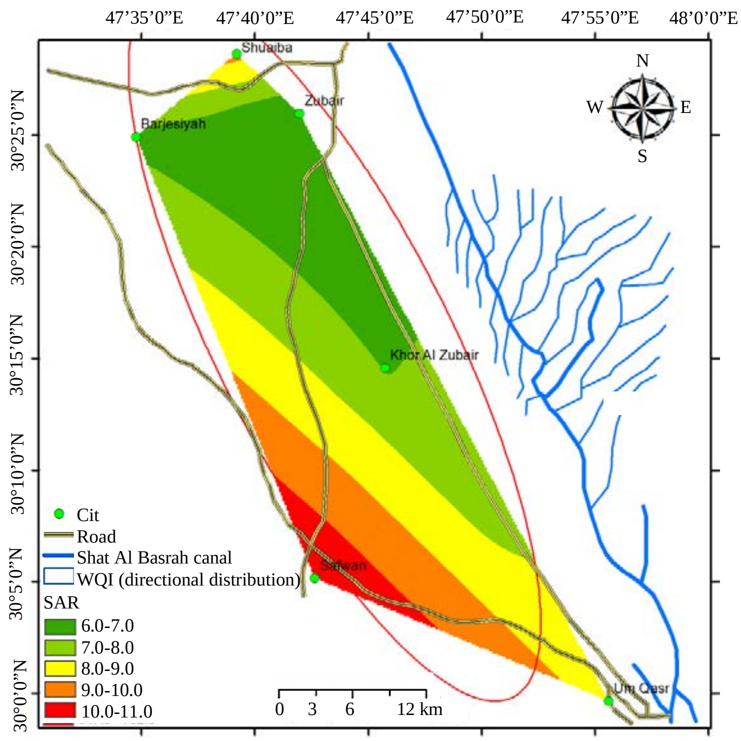

Fig. 4: Distribution of GWQI over study area

Table 9: Water quality scale

Water quality	WQI (Yisa and Jimoh, 2010)	WQI (Yogendra and puttaiah)
Excellent	<50	<50
Good	50-100	50-100
Poor	100-200	100-200
Very poor	200-300	200-300
Unsuitable	>300	>300

distribution of features is extended and then has a specific orientation (Fig. 2-4 for directional distribution of SAR, Na% and GQWI, respectively). Through Fig. 2 and 3, the general trend of directional distribution of Na^+ concentration is from the northwest to the southeast in other words with align of the Shatt Al-Basrah Canal (drainage canal) there is a clear effect of the canal on the adjacent areas lead to increase the concentration of Na^+. The groundwater flow direction in the studied area has a clear effect on the deterioration of the quality of groundwater along with the direction of groundwater path lines towards the Arabian Gulf near Um Qasr (Fig. 4).

CONCLUSION

PH values in the study area ranged from 7.78-8.1, according to these values, all sampling sites lie under the acceptable range. The minimum concentration of TDS (4079 mg/L) in Zubair, the maximum concentration of TDS (10969 mg/L) in Safwan while the EC values ranged from 6180 (μS/cm) in Zubair area to 16620 (μS/cm) in Safwan area. According to SAR classification, the values of SAR varied from first class (excellent) to the second class (good). Na% values ranged from 37.29-60.54%, it is found that the type of groundwater ranged from good to doubtful class. The groundwater quality of studied area based on groundwater quality index lies under unsuitable class. Based on the directional distribution method (standard direction ellipse), the general trend of directional distribution of Na^+ concentration is from the northwest to the southeast in other words with align of the Shatt Al-Basrah Canal (drainage canal), there is a clear effect of the canal on the adjacent areas lead to increase the concentration of Na^+. The groundwater flow direction (from the Northwest to the Southeast) has a clear effect on the deterioration of the quality of groundwater along with the direction of groundwater path lines towards the Arabian Gulf near Um Qasr.

REFERENCES

Al-Aboodi, A.H., 2017. Estimation of monthly mean reference evapotranspiration using gene expression programming. Kufa J. Eng., 8: 37-50.

Anonymous, 1998. Drinking water specifications. Bureau of Indian Standards, Delhi, India.

Babiker, I., M.A.A. Mohamed and T. Hiyama, 2007. Assessing groundwater quality using GIS. Water Res. Manage., 21: 699-715.

Backman, B., D. Bodis, P. Lahermo, S. Rapant and T. Tarvainen, 1998. Application of a groundwater contamination index in Finland and Slovakia. Environ. Geol., 36: 55-64.

Brown, R.M., N.I. McClelland, R.A. Deininger and R.G. Tozer, 1970. A water quality index: Do we dare?. Water Sewage Works, 117: 339-343.

Davis, S. N. and R.J. DeWiest, 1966. Hydrogeology. John Wiley and Sons, Hoboken, New Jersey, USA., ISBN:9780471199007, Pages: 463.

Deshmukh, K.K. and S.P. Aher, 2016. Assessment of the impact of municipal solid waste on groundwater quality near the Sangamner City using GIS approach. Water Resour. Manage., 30: 2425-2443.

Ishaku, J.M.,A.S. Ahmed and M.A. Abubakar, 2012. Assessment of groundwater quality using water quality index and GIS in Jada, Northeastern Nigeria. Intl. Res. J. Geol. Min., 2: 54-61.

Kim, G., 2010. Integrated consideration of quality and quantity to determine regional groundwater monitoring site in South Korea. Water Resour. Manage., 24: 4009-4032.

Kumari, S. and J. Rani, 2014. Assessment of water quality index of ground water in Smalkhan, Haryana. Intl. J. Latest Res. Sci. Technol., 3: 169-172.

Lescesen, I., M. Pantelic, D. Dolinaj, V. Stojanovic and D. Milosevic, 2015. Statistical analysis of water quality parameters of the drina river (West Serbia), 2004-11. Polish J. Environ. Stud., 24: 555-561.

Mohanty, S.K., 2004. Water Quality Index of Four Religious Ponds and its Seasonal Variation in the Temple City, Bhuvaneshwar. In: Water Pollution, Kumar, A. (Ed.). Aph Publishing Corporation, Delhi, India, pp: 211-218.

Nives, S.G., 1999. Water quality evaluation by index in Dalmatia. Water Res., 33: 3423-3440.

Ramakrishnaiah, C.R., C. Sadashivaiah and G. Ranganna, 2009. Assessment of water quality index for the groundwater in Tumkur Taluk, Karnataka State, India. E-J. Chem., 6: 523-530.

Ravikumar, P., M.A. Mehmood and R.K. Somashekar, 2013. Water quality index to determine the surface water quality of Sankey tank and Mallathahalli lake, Bangalore urban district, Karnataka, India. Applied Water Sci., 3: 247-261.

Rivard, C., Y. Michaud, R. Lefebvre, C. Deblonde and A. Rivera, 2008. Characterization of a regional aquifer system in the Maritimes Basin, Eastern Canada. Water Resour. Manage., 22: 1649-1675.

Sadik, H.H., 1977. Sedimentological investigation of the Dibdibba formation, Southern and Central Iraq. Ph.D Thesis, University of Baghdad, Baghdad, Iraq.

Sahu, P. and P.K. Sikdar, 2008. Hydrochemical framework of the aquifer in and around East Kolkata wetlands, West Bengal, India. Environ. Geol., 55: 823-835.

Shahid, S.U. and J. Iqbal, 2016. Groundwater quality assessment using averaged water quality index: A case study of Lahore City, Punjab, Pakistan. Proceedings of the IOP International Conference on Series: Earth and Environmental Science Vol. 44, October 17-19, 2016, IOP Publishing, Bristol, UK., pp: 1-6.

Sibson, R., 1981. A Brief Description of Natural Neighbor Interpolation. In: Interpolating Multivariate Data, Barnett, V. (Ed.). John Wiley & Sons, New York, USA., pp: 21-36.

Soltan, M.E., 1999. Evaluation of groundwater quality in Dakhla Oasis (Egyptian Western Desert). Environ. Monitor. Assess., 57: 157-168.

Spalding, R.F. and M.E. Exner, 1980. Areal, vertical and temporal differences in ground water chemistry: I. Inorganic Constituents. J. Environ. Qual., 9: 466-479.

Stigter, T.Y., L. Ribeiro and A.M.M. Carvalho Dill, 2006b. Application of a groundwater quality index as an assessment and communication tool in agro-environmental policies-Two Portuguese case studies. J. Hydrol., 327: 578-591.

Stigter, T.Y., L. Ribeiro and A.M.M. Carvalho Dill, 2006a. Evaluation of an intrinsic and a specific vulnerability assessment method in comparison with groundwater salinisation and nitrate contamination levels in two agricultural regions in the south of Portugal. J. Hydrogeol., 14: 79-99.

Todd, D.K., 1980. Groundwater Hydrology. 2nd Edn., John Wiley and Sons, New York, ISBN-10: 047187616X.

WHO., 2011. Guidelines for Drinking Water Quality. 4th Edn., World Health Organization, Geneva.

Wilcox, L.V., 1955. Classification and Use of Irrigation Waters. 1st Edn., United States Department of Agriculture, Washington, DC., Pages: 19.

Yisa, J. and T. Jimoh, 2010. Analytical studies on water quality index of river landzu. Am. J. Applied Sci., 7: 453-458.