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Creating the Distribution Map of Groundwater for Drinking Uses Using Physio-Chemical Variables; Case Study: Al-Hilla City, Iraq

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Abstract Surface water and groundwater are significant for population and other activities due to the decreasing surface water flow toward Iraq. Therefore, there is a need to analyze groundwater's quality and classification and its applicability as an alternative in various human activities in the study area. This study utilized the groundwater quality index model for drinking uses (GW.Q.I.) and entered the resulting values in the GIS environment. This model was applied to 56 wells in Al-Hillah city by measuring twelve variables in each well. The measured variables were calcium (Ca), magnesium (Mg), sodium (Na), chloride (Cl), sulfate (SO4), bicarbonate (HCO_3), total hardness (TH), total dissolved solids (TDS), nitrate (NO_3), and electric conductivity (EC). The prediction map of GW.Q.I. was produced in the GIS. Then, the distributing map was divided into six categories based on the suitability of groundwater for drinking uses. The areas' values of six categories with their ratings were about 5 km^2 (excellent), 122 km^2 (good), 610 km^2 (poor), 63 km^2 (very poor), 36 km^2 (contaminated), and 24 km^2 (very contaminated). For the entire study area, the average value of the GW.Q.I. was 177, classified as poor for drinking uses.

Keywords Distributing map · Groundwater quality index · Drinking uses · GIS

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1 Introduction

Many factors affect the water quality index (W.Q.I.), including population growth rate, climate change, and expanded industrial and agriculture activities, which caused a significant decrease in quality of water, which represented a local and global challenge (Krishan et al., 2016). Various physical and chemical variables were adopted by researchers to evaluate the W.Q.I. for drinking uses. Walsh and Wheeler, (2012) illustrated that multiple factors should be considered when analyzing the water body's quality. The physicochemical variables relate to the level of abundance of water. Also, the concentrations of variables in the water body significantly affect evaluating the W.Q.I. Furthermore, studying these variables one-variable-at-a-time does not show a comprehensive vision for the W.Q.I. Moreover, water treatment is required if the variables do not meet the region's standards (Bouderbala, 2017).

Numerical or mathematical methods can calculate the W.Q.I. for drinking uses. These methods can give a broad view of the groundwater quality in a specific area timelessly and effortlessly and, therefore, avoid wells in areas where groundwater is unsuitable to use (Alobaidy et al., 2010). Water source characteristics directly affect groundwater quality and its utilization suitability. Continuous monitoring of the chemical and physical parameters should be maintained and controlled to keep the groundwater quality in a good state to be used.

Recently, the water shortage crisis started to arise in Iraq due to climate change, construction of dams upriver, wars, and unsystematic drinking water use. This shortage raised the need to invest in groundwater resources. Thus, quality analysis is required to check its suitability for use. GIS is highly capable of creating wells' distribution maps using relevant variables. These maps help specialists cross-examine water quality across multiple sites (Chabuk et al., 2020).

The groundwater quality index method is the most widespread method for assessing water quality in developing countries to maintain water quality. It represents an essential storage strategy for countries' future uses when decreasing the surface water level. It is a permanent source for groundwater research as it is one of Iraq's most critical natural resources. The suitability of groundwater in the city of Hillah for the different uses was studied for construction purposes mainly. The groundwater level fluctuations as well as its chemical composition at Hilla city was carefully considered. Two negative influences have a combined effect on concept tolerance. All tested samples for the groundwater showed that they are not suitable for domestic, animal as well as some industrial purposes.

Chabuk et al., (2020) evaluated the groundwater for irrigation in Al-Hillah city by applying the water quality index for the irrigation model (WQIIR) in the GIS environment. They measured Ca, Mg, Cl, EC, HCO_3, Na, and SAR in 48 wells distributed in different areas in Al-Hillah city. The results based on the predicted maps in 2016

showed that the values of areas in 2016 were about 48.4 km^2, 399 km^2, 384.3 km^2, 28.1 km^2, and 0.2 km^2. These categories were classified for irrigation (respectively) as a severe restriction, high restriction, moderate restriction, low restriction, and no restriction.

The W.Q.I. method was applied to evaluate the groundwater quality by many researchers in various study areas. Alikhan et al., (2020) estimated the groundwater quality at five wells in Al Najaf city, Iraq, in 2017 using nine parameters (pH, EC, TDS, Ca, Mg, Cl, Na, K, and SO_4). The study found that the total value of the W.Q.I. was classed under a poor rating.

Mohammed et al., (2020) adopted the W.Q.I. method to evaluate groundwater quality in the Domiz refugee camp, Duhok governorate. Twenty-four variables were measured in 8 wells. The results showed that the W.Q.I. values were rated as very poor in well 1; poor in wells 2 and 3; good in wells 4, 6, and 7; and excellent in wells 5 and 8.

Othman and Ibrahim, (2021) studied the quality of groundwater for drinking and other domestic uses and the activities of agriculture in Erbil city, Iraq, using the Canadian method for water quality index. They measured twenty-two variables in 16 wells in December/2016, and during the three months of March, June, and September/2017. These variables are pH, EC, TH, Ca, Mg, alkalinity, Cl, DO, BOD_5, Na, K, SO_4, PO_4, NO_3, oil and grease, Zn, Cu, Fe, Ni, Pb, Cd, and Hg. The results showed that the total value of W.Q.I. was 38.9, which classified the groundwater quality in the study area as poor quality.

The purpose of creating a new map of groundwater for drinking uses is that the study zone does not have a map for groundwater. The study zone has been affected by the global warming problem which led to searching for another way to cover the shortage. The map will be a document to help the researchers and the specialists. Also, the future plan for the Governorate is to secure additional drinking water sources when necessary and help with future suburbs of the city. Moreover, the map is an easy way to show the groundwater to users.

The research is interested in studying the suitability of the groundwater in Al-Hillah city for drinking and household uses by measuring the available variables within 56 wells from various areas. This study aims to create the prediction map using the groundwater quality index model for drinking uses (GW.Q.I.). Then, the values of GW.Q.I. will enter within the interpolation technique IDW in the GIS to produce the prediction map.

2 Methodology

2.1 Study Area

Al-Hillah city is situated between latitude 32° 29′ 00" N and longitude 44° 26′ 00". Al-Hillah city represents the capital of Babylon Governorate. Al-Hillah city includes three major cities: Al-Hillah center, Abi-Ghraq, and Al-Kifll (Fig. 1).

Al-Hillah city is situated in an arid region and its area of 860 km^2. According to the Iraqi Ministry of Planning, (2017)Al-Hillah city has a population of nearly 993,000 inhabitants in 2020. The climate of Al-Hillah city is fluctuating seasonally and daily. The average speed of wind is 7.2 km/h year. The average annual rainfall in this area is about 100 mm, with an average annual relative humidity of 45%. The temperature is changing from more than 50 °C during the summer to over 0 °C during the winter (Iraqi Ministry of transportation constitutions, 2019).

The hydrogeology of Al-Hillah city, Babylon Governorate, is situated in the middle of Iraq in the aquifer of Mesopotamia zone (MZ) in a large flat plain (Al-Madhlom et al., 2020; Sissakian, 2013). The elevation of MZ ranges between 1 and 200 m above mean sea level (a.m.s.l.). The Mesopotamia region is covered mainly by the Quaternary sediments (Al-Madhlom et al., 2020). Al-Hillah city is positioned within the Mesopotamia plan silt zone covered by the Holocene Sequence with a thickness of about 20 m. Its primary compositions are silty clay, loamy sand, and sandy loam soil (Tyagi et al., 2013). The groundwater in the study area is shallow with ranges of 0.4–4.5 m (Chabuk et al., 2021) (Fig. 2) and flows with the trend of surface drainage from northwest to southeast (Al-Jiburi & Al-Basrawi, 2011).

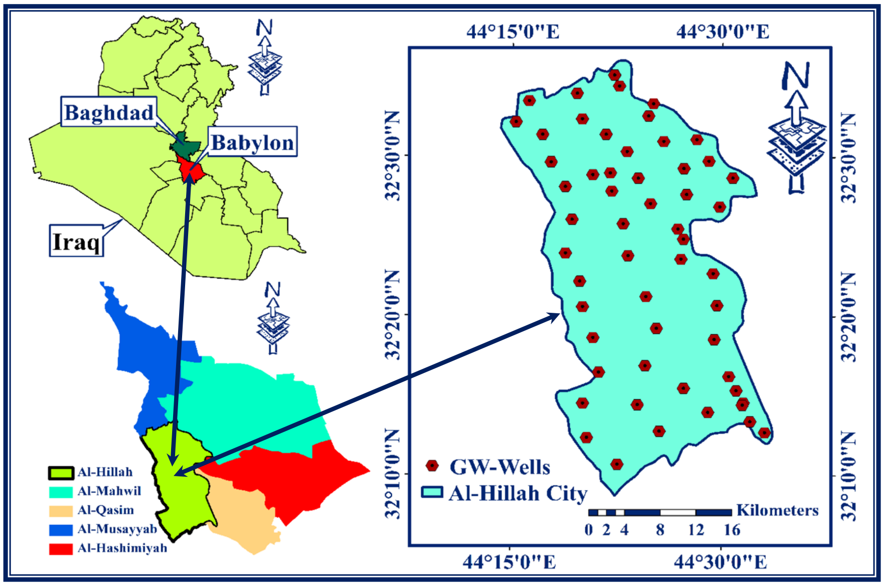

Fig. 1 Map of the study area showing the sampling sites

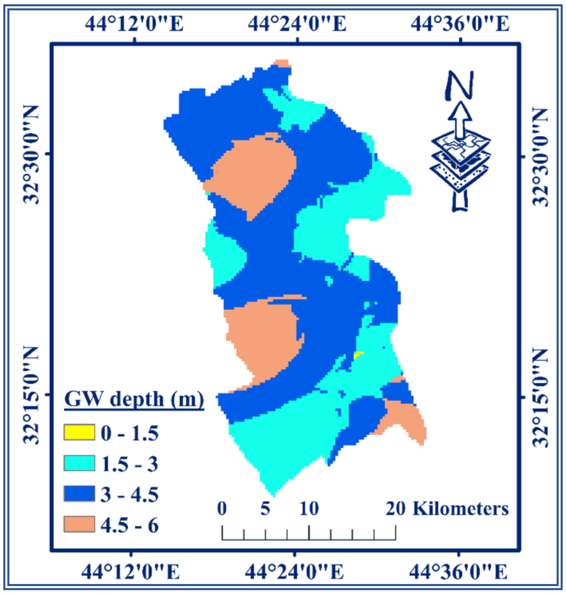

Fig. 2 Groundwater depths throughout Al-Hillah city (Chabuk et al., 2021)

Table 1 Classification of G.W.Q.R. based on values of GW.Q.I. (Ali, 2017; Alsaqqar et al., 2015)

Value of GW.Q.I	Water quality rating (GW.Q.R.)
< 50	Excellent (E-GW)
50–100	Good (G-GW)
100–200	Poor (P-GW)
200–300	Very poor (Vp-GW)
300–400	Contaminated (C-GW)
> 400	Vary contaminated (Vc-GW)

The groundwater level rises during the winter and spring season due to increased rainfall and reduction in evaporation. The type of groundwater varies from sulfate to chloride based on the groundwater level and the quantity of recharge by runoff from discharge areas (Al-Jiburi & Al-Basrawi, 2011). In general, the groundwater, located near/around the surface water, has a good quality for use.

2.2 Prediction Maps in GIS Using the Interpolation Method (IDW)

To generate the interpolation map of the groundwater quality index for drinking uses for each variable, the interpolation inverse distance weighted technique (IDWT) was applied in the GIS. The interpolation method is used to estimate the unidentified point at a specific position based on the values of defined points near the unidentified points. The spatial interpolation technique is applied to produce interpolation maps of groundwater quality rather than other techniques (e.g., Kriging, Topo to Raster). The IDW technique gave better and more accurate results than other spatial ones, according to Abbas, (2013).

The IDWT is determined using Eq. (1) (Panhalkar & Jarag, 2016) as follows:

$$SE_0 = \frac{\sum_{i=1}^{n} N_i \frac{1}{D_i^p}}{\sum_{i=1}^{n} \frac{1}{D_i^p}} \quad (1)$$

where SE_0 is the estimated value of unidentified points; N_i is the value of the defined point; D_i is the distance

Table 2 Calculating of groundwater quality index for drinking uses for each variable

Variables	C_i	C_o	STV_i	IW_i	Su-Ii	IWi × Su-Ii	GW.Q.I
Na	1106.5	0	200	0.005	553.23	2.77	553.2
TDS	6038.3	0	500	0.002	1207.66	2.42	1207.7
EC	8676.3	0	1000	0.001	867.64	0.87	867.6
CL	1449.6	0	250	0.004	579.84	2.32	579.8
HCO_3	352.4	0	200	0.005	176.22	0.88	176.2
SO_4	1732.3	0	250	0.004	692.94	2.77	692.9
Ca	334.8	0	75	0.0133	446.38	5.95	446.4
Mg	231.0	0	50	0.02	462.11	9.24	462.1
NO_3	11.9	0	12	0.0833	99.40	8.28	99.4
K	11.8	0	10	0.1	118.21	11.82	118.2
PH	7.67	7	7.5	0.1333	17.76	2.37	17.8

Table 3 Concentrations of GW in 56 wells in Al-Hillah city (Iraqi Ministry of Water Resources, 2017)

Well	Na	TDS	EC	CL	HCO_3	SO_4	Ca	Mg	NO_3	K	PH
W1	325	2400	3100	610	260	700	144	222	2	0	7.9
W2	4140	17,890	25,200	2841	933	7872	802	450	5	121	7.7
W3	183	886	1340	255	122	247	118	65	1	2	7.3
W4	713	3453	5290	1029	110	1250	188	185	13	0	8.2
W5	183	1324	2040	347	120	257	178	62	1	4	7.7
W6	240	1200	1900	370	390	230	90	80	0	0	7.6
W7	851	5175	6600	1065	244	2352	230	389	10	0	7.8
W8	75	735	1200	137	475	64	112	57	0	0	7.3
W9	327	2136	3300	678	265	379	217	135	9	5	7.2
W10	36	480	750	85	220	120	84	42	10	0	7.8
W11	186	1030	1332	183	122	326	49	22	2	1	7.1
W12	173	821	1250	244	116	243	118	62	1	2	7.3
W13	252	1678	2500	260	209	523	137	50	1	1	7.3
W14	3000	13,800	20,600	1846	616	5760	503	305	7	11	7.2
W15	276	1885	3630	311	208	585	150	60	1	1	8.1
W16	748	4529	5700	959	244	2016	160	389	6	0	7.8
W17	169	1005	1520	298	195	209	160	62	2	4	7.3
W18	1380	5437	8500	2023	590	1248	136	360	0	0	8.2
W19	155	681	1030	190	88	208	104	46	1	1	7.3
W20	198	1357	1857	230	152	379	78	44	1	1	7.9
W21	171	758	1180	227	116	213	119	52	1	2	7.3
W22	182	1050	1605	142	122	326	29	21	0	1	8.4
W23	226	1507	2050	187	115	494	131	44	2	1	8.5
W24	1601	7958	12,380	3202	180	372	350	210	1	9	7.2
W25	70	700	1080	130	460	90	80	80	15	0	8.0
W26	1129	6089	9180	1219	950	1810	479	200	2	23	8.2
W27	227	976	1500	294	128	291	138	55	1	4	7.6
W28	220	959	1450	283	126	302	137	59	1	3	7.2
W29	298	2900	3740	529	293	724	274	144	0	3	8.5
W30	202	822	1400	138	415	182	36	60	0	0	7.8
W31	200	1542	1800	142	402	720	134	136	0	0	7.6
W32	1175	6328	9820	2674	190	300	420	210	1	7	7.5
W33	78	453	890	183	280	180	24	48	0	0	7.4
W34	271	2291	3530	610	116	325	86	177	0	5	7.3
W35	117	2888	4447	45	150	1120	256	80	40	0	7.4
W36	430	2790	4300	575	260	1140	352	145	50	0	7.5
W37	772	3300	5000	248	146	1920	84	153	5	0	8.0
W38	1435	5962	7500	1065	220	2880	180	261	10	23	7.8
W39	73	400	630	74	125	124	56	14	0	0	7.6
W40	1564	6702	8710	1225	101	3040	400	214	209	0	8.3
W41	254	2030	3060	532	284	436	184	108	0	2	8.5
W42	1998	11,720	17,700	1704	111	3828	422	268	5	11	7.4
W43	166	864	1300	257	108	197	118	59	1	2	7.9
W44	1109	7283	11,300	2725	240	390	405	214	1	8	7.6
W45	1242	6303	8080	1296	82	2800	548	239	178	0	8.1
W46	3939	12,500	18,240	3000	990	5579	100	500	0	4	8.1

Table 3 (continued)

Well	Na	TDS	EC	CL	HCO_3	SO_4	Ca	Mg	NO_3	K	PH
W47	217	1288	1960	350	128	258	143	68	2	5	7.1
W48	85	300	400	54	77	84	3	10	0	0	7.4
W49	254	7204	10,550	1136	432	456	302	170	10	195	7.2
W50	900	9058	12,090	1491	2019	1930	822	430	5	9	7.7
W51	2873	28,222	44,000	12,729	250	1100	3082	1300	1	28	7.8
W52	2100	25,624	39,100	4295	1200	2800	1200	600	0	5	7.5
W53	5021	27,632	41,300	4926	1263	10,000	1470	901	0	6	6.3
W54	3118	16,018	23,700	2062	744	6192	604	366	6	31	7.8
W55	4140	17,890	25,200	2841	933	7872	802	450	5	121	7.7
W56	10,495	39,933	47,060	14,626	302	11,568	1020	1806	43	0	7.9
Aver	1106	6038	8676	1450	352	1732	335	231	12	12	8
SD	1763.7	8279.3	11,560.9	2633.8	370.5	2600.4	481.1	312.9	36.8	33.8	0.436
WHO 2017	200	500	1000	250	200	250	75	50	10	12	7.5

between SE_0 and N_i; n is the number of N_i entered in the estimation process; ans p is the power value ≥ 1.

2.3 Method of Calculating Weights of Groundwater Quality Index for Drinking Uses

In this research, the weighted arithmetic method is employed to calculate the groundwater quality index for drinking uses. Twelve variables were used for the selected fifty-six wells within Al-Hillah city because the chosen variables are very significant to calculate the water quality index for different purposes. The groundwater quality index for drinking uses for selected wells in Al-Hillah city was calculated using the following Eqs. (2–4) (Tyagi et al., 2013):

$$Su - I_i \left(\frac{C_i - C_o}{ST_i - C_o} \right) \times 100 \quad (2)$$

$$\mathrm{IW_i} = \frac{1}{\mathrm{STV_i}} \quad (3)$$

$$\mathrm{GW.Q.I} = \frac{\sum \mathrm{SUIi} \times \mathrm{IWi}}{\sum \mathrm{IWi}} \quad (4)$$

where $Su\text{-}I_i$ is the sub-index of the ith variable, IW_i is the inverse weight of the standard value ($\mathrm{STV_i}$) of the ith variable, $\mathrm{STV_i}$ is the standard value of the ith variable (WHO, 2017), $\mathrm{C_i}$ is the measured concentration value for the ith variable, C_o is the ideal value for each variable in water that has zero value, excluding the pH value which is equal to 7.

For each well within Al-Hillah city, the water quality rating (GW.Q.R.) was given the deserve classification based on the category of the GW.Q.I. according to Alsaqqar et al., (2015) and Ali, (2017) (see Table 1).

The steps of calculating the GW.Q.I. for drinking uses for each variable can be seen in Table 2. The reading of the measured variables from sixty-five wells in Al-Hillah city in 2018 is shown in Table 3 (Iraqi Ministry of Water Resources, 2017).

3 Results and Discussion

This part is divided into three sections depending on the methodology approach. These sections evaluate the concentration values of variables measured in the selected wells, calculating the groundwater quality index for drinking uses for each well in the study area, and creating the maps of the GW.Q.I. and GW.Q.R. for the whole Al-Hillah city using the GIS.

3.1 Prediction Maps for Variables of Groundwater

In the current study, the prediction maps for twelve physicochemical variables measured from the network of wells distributed throughout Al-Hillah city were produced. Fifty-six wells were used to generate prediction maps using the interpolation method in the ArcGIS (10.5) software.

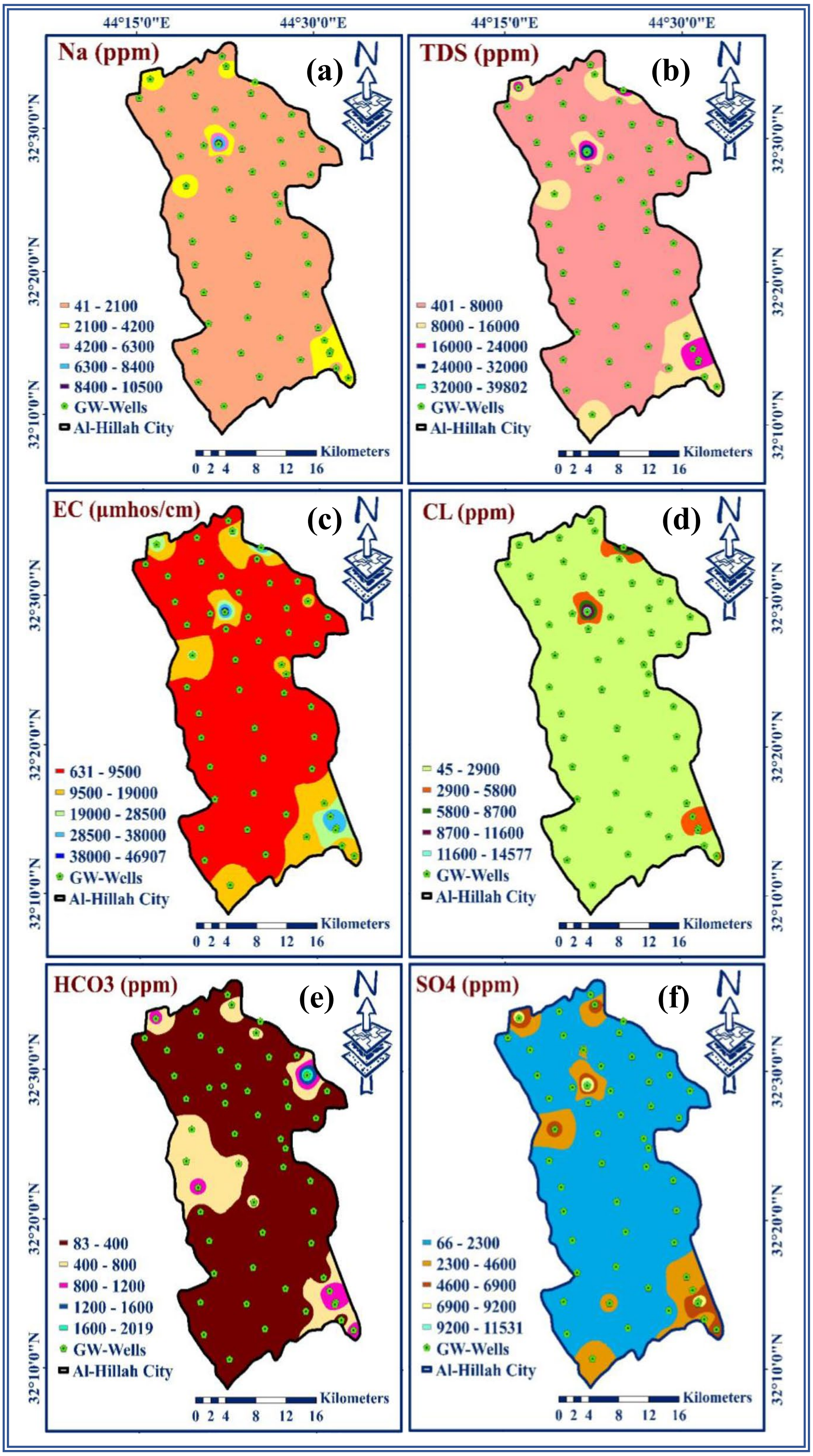

Fig. 3 Interpolation maps using IDW method in GIS of **a** Na; **b** TDS; **c** EC; **d** Cl; **e** HCO3; and **f** SO4

Fig. 4 Interpolation maps using IDW method in GIS of **a** Ca; **b** Mg; **c** NO3; **d** K; and **e** pH

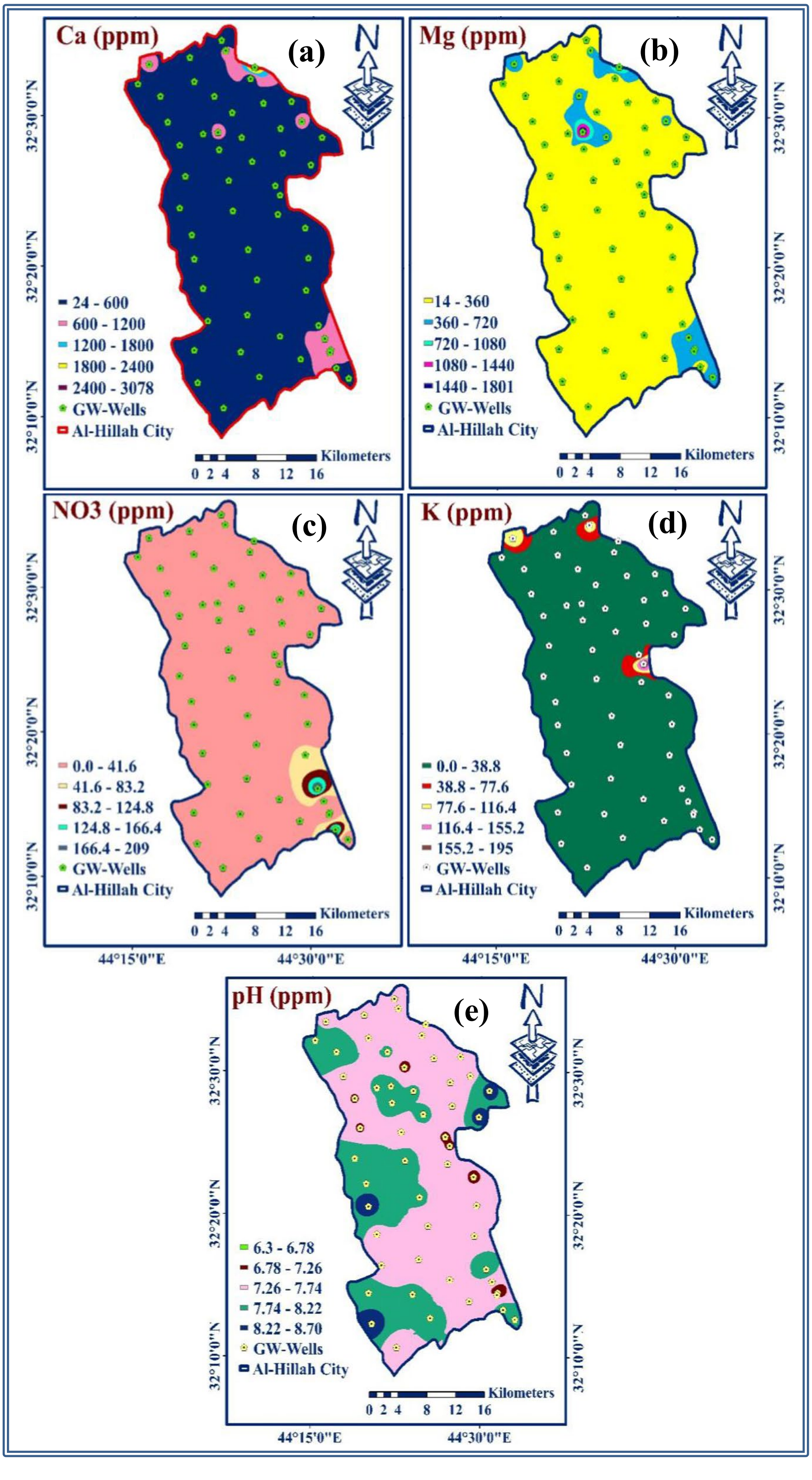

Table 4 Area of each category for produced maps of the selected variables

Variables	Categories				
	Cat-1	Cat-2	Cat-3	Cat-4	Cat-5
Na	802.2	52.8	2.8	1.3	0.90
TDS	733.9	104.6	18.2	2.4	0.9
EC	684.1	141.3	24.5	8.7	1.4
Cl	827.3	25.9	1.9	3.8	1.1
HCO_3	696.4	136.1	23.1	2.8	1.6
SO_4	723.8	103.7	26.2	5.3	1.0
Ca	810.4	46.4	2.0	0.7	0.5
Mg	793.0	60.0	4.2	1.9	0.9
NO_3	817.1	28.8	8.7	3.8	1.6
K	832.2	17.4	7.8	1.8	0.8
pH	0.23	11.68	552.13	269.48	26.48

For the chosen variables of groundwater in the study area, the prediction maps for the sodium (Na), total dissolved solids (TDS), electrical conductivity (EC), chloride (Cl), bicarbonates (HCO_3^{-1}) sulfates (SO_4), calcium (Ca), magnesium (Mg), nitrate (NO_3), potassium (K), and pH can be seen in Figs. 3 and 4.

In Fig. 3a, b, c and d, the range values of Na, TDS, EC, and Cl that resulted from the interpolation maps using the IDW method in GIS were (respectively) 41–10,500 mg/l, 401–39,802 mg/l, 631–46,907 μmhos/cm, and 45–14,577 mg/l. For the variables of Na and Cl, category-1 with ranges of 41–2100 mg/l and 45–2900 mg/l covered the big area of the total study area of 93% and 96% respectively. The ranges of 400–8000 mg/l for TDS and 631–9500 for EC represented the most distribution values in the study area (see Fig. 3b and c).

The variable concentrations of HCO_3 and SO_4, distributed throughout the Al-Hillah city after interpolation within their maps ranged from 83 to 2019 mg/l, and from 66 to 11,531 mg/l, respectively, are shown in Fig. 3e and f. The range of 83–400 mg/l for HCO_3 concentration was comprised 81% of the entire area, while 84% of the range of 66–2300 mg/l distributed throughout the prediction map of Al-Hillah city for SO_4 concentration.

The readings of variable concentrations Ca, Mg NO_3, and K were ranged between 24 and 3078 mg/l, 14 and 1801 mg/l, 0 and 209 mg/l, and 0 and 109 mg/l, respectively. These variables were distributed throughout the study area after interpolation for the readings of 56 wells. Figure 4a, b, c and d shows that the category-1 with ranges (mg/l) of 24–600, 14–360, 0–41.6, and 0–38.8 covered higher percentage of the study area 94% (Ca), 92% (Mg), 95% (NO3), and 97% (K). The range of the predicted map of pH that was divided into five categories was 6.3–8.7. The ranges of 7.26–7.74 and 7.74–8.22 represented together 95% of the total area (Fig. 4e).

The proportion areas of each category for the produced maps for eleven variables (Na, TDS, EC, Cl, HCO_3, SO_4, Ca, Mg, NO_3, K, and pH) can be seen in Table 4.

3.2 Groundwater Quality Index for Drinking Uses (GW.Q.I.)

The groundwater quality index for drinking uses was calculated using the method of weighted arithmetic at the selected wells based on Eqs. (2, 3, 4). The GW.Q.I. values for the selected wells were calculated using the weighted arithmetic method (Table 1). All the parameters applied in this study are presented in Table 3 and were significant in this classification for the groundwater quality index. The GW.Q.I. values were classified based on the values of variables measured in the selected wells, as shown in Table 5. The sign of "×" referred to that put reading of variable in Table 5 over allowable standards limit, while the word "OK" meant this value of reading within the allowable limit. For instance, the groundwater quality index for drinking uses for well 5 was 82.3 and rated as good because the measured variables of HCO_3, NO_3, K, and pH were within the standards limit. These variables have significant effects on the value of the GW.Q.I. For well 2, all measured variables except NO_3 and pH were over the standards limit; therefore, the value of the GW.Q.I. was 483.7 and rated as very contaminated for drinking uses. The value of the GW.Q.I. in well 48 was 32.1, and it was classified as excellent for drinking uses because all measured readings of variables were within the standards limit. Table 5 shows that most values of the TDS, EC, and Cl were higher than the allowable limit. These values indicated the groundwater in the study area was salinity. All readings of pH measured in the selected wells were the standard limit of 6.5–8.5.

Table 6 shows the values of the groundwater quality index for the variables of Na, TDS, EC, Cl, SO_4,

Table 5 Classification of GW.Q.I. for drinking uses; the variables' values within the allowable limit

Well	Na	TDS	EC	CL	HCO_3	SO_4	Ca	Mg	NO_3	K	PH	GWQI	GWQR
W1	×	×	×	×	×	×	×	×	OK	OK	OK	113.9	P-GW
W2	×	×	×	×	×	×	×	×	OK	×	OK	483.7	Vc-GW
W3	OK	×	×	×	OK	OK	×	×	OK	OK	OK	46.2	E-GW
W4	×	×	×	×	OK	×	×	×	×	OK	OK	170.8	P-GW
W5	×	×	×	×	OK	×	×	×	OK	OK	OK	82.3	G-GW
W6	×	×	×	×	×	OK	×	×	OK	OK	OK	64.7	G-GW
W7	×	×	×	×	×	×	×	×	OK	OK	OK	166.9	P-GW
W8	OK	×	×	OK	×	OK	×	×	OK	OK	OK	38.8	E-GW
W9	×	×	×	×	×	×	×	×	OK	OK	OK	84.7	G-GW
W10	OK	OK	OK	OK	×	OK	×	OK	OK	OK	OK	96.3	G-GW
W11	OK	×	×	OK	OK	×	OK	OK	OK	OK	OK	24.9	E-GW
W12	OK	×	×	OK	OK	OK	×	×	OK	OK	OK	45.6	E-GW
W13	×	×	×	×	×	×	×	OK	OK	OK	OK	47.1	E-GW
W14	×	×	×	×	×	×	×	×	OK	OK	OK	188.4	P-GW
W15	×	×	×	×	×	×	×	×	OK	OK	OK	107.4	P-GW
W16	×	×	×	×	×	×	×	×	OK	OK	OK	149.2	P-GW
W17	OK	×	×	×	OK	OK	×	×	OK	OK	OK	54.9	G-GW
W18	×	×	×	×	×	×	×	×	OK	OK	OK	167.1	P-GW
W19	OK	×	×	OK	OK	OK	×	OK	OK	OK	OK	40.4	E-GW
W20	OK	×	×	OK	OK	×	×	OK	OK	OK	OK	84.7	G-GW
W21	OK	×	×	OK	OK	OK	×	×	OK	OK	OK	44.3	E-GW
W22	OK	×	×	OK	OK	×	OK	OK	OK	OK	OK	111.8	P-GW
W23	×	×	×	OK	OK	×	×	OK	OK	OK	OK	133.5	P-GW
W24	×	×	×	×	OK	×	×	×	OK	OK	OK	112.7	P-GW
W25	OK	×	×	OK	×	OK	×	×	×	OK	OK	130.3	P-GW
W26	×	×	×	×	×	×	×	×	OK	×	OK	215.3	Vp-GW
W27	×	×	×	×	OK	×	×	×	OK	OK	OK	72.2	G-GW
W28	×	×	×	×	OK	×	×	×	OK	OK	OK	41.9	E-GW
W29	×	×	×	×	×	×	×	×	OK	OK	OK	155.6	P-GW
W30	×	×	×	OK	×	OK	OK	×	OK	OK	OK	72.5	G-GW
W31	OK	×	×	OK	×	×	×	×	OK	OK	OK	74.1	G-GW
W32	×	×	×		OK	×	×	×	OK	OK	OK	126.0	P-GW
W33	OK	OK	OK	OK	×	OK	OK	OK	OK	OK	OK	39.8	E-GW
W34	×	×	×	×	OK	×	×	×	OK	OK	OK	64.2	G-GW
W35	OK	×	×	**OK**	OK	×	×	×	×	OK	OK	168.6	P-GW
W36	×	×	×	×	×	×	×	×	×	OK	OK	219.4	Vp-GW
W37	×	×	×	OK	OK	×	×	×	OK	OK	OK	126.3	P-GW
W38	×	×	×	×	×	×	×	×	OK	×	OK	200.9	Vp-GW
W39	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	50.1	E-GW
W40	×	×	×	×	OK	×	×	×	×	OK	OK	738.2	Vc-GW
W41	×	×	×	×	×	×	×	×	OK	OK	OK	157.2	P-GW
W42	×	×	×	×	OK	×	×	×	OK	OK	OK	167.4	P-GW
W43	OK	×	×	×	OK	OK	×	×	OK	OK	OK	88.2	G-GW
W44	×	×	×	×	×	×	×	×	OK	OK	OK	136.7	P-GW
W45	×	×	×	×	OK	×	×	×	×	OK	OK	646.4	Vc-GW
W46	×	×	×	×		×	×	×	OK	OK	OK	233.9	Vp-GW
W47	×	×	×	×	OK	×	×	×	OK	OK	OK	43.0	E-GW

Table 5 (continued)

Well	Na	TDS	EC	CL	HCO_3	SO_4	Ca	Mg	NO_3	K	PH	GWQI	GWQR
W48	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	32.1	E-GW
W49	×	×	×	×	×	×	×	×	OK	×	OK	461.2	Vc-GW
W50	×	×	×	×	×	×	×	×	OK	OK	OK	213.8	Vp-GW
W51	×	×	×	×	×	×	×	×	OK		OK	523.4	Vc-GW
W52	×	×	×	×	×	×	×	×	OK	OK	OK	258.5	Vp-GW
W53	×	×	×	×	×	×	×	×	OK	OK	OK	348.0	C-GW
W54	×	×	×	×	×	×	×	×	OK	×	OK	285.4	Vp-GW
W55	×	×	×	×	×	×	×	×	OK	×	OK	483.7	Vc-GW
W56	×	×	×	×	×	×	×	×	×	OK	OK	665.6	Vc-GW
WHO	200	500	1000	250	200	250	75	50	10	12	7.5		

E, excellent; *G*, good; *P*, poor; *VP*, very poor; *C*, contaminated; *VC*, vary contaminated; *OK*, within the allowable limit; ×, over the allowable limit

Ca, and Mg which were (respectively) 553.2, 1207.7, 867.6, 579.8, 692.9, 446.4, and 462.1 and they classified as very contaminated rating (Vc-GW). The variables HCO_3 and K were rated as poor (P-GW) based on their values of groundwater quality index of 176.2 and 118.2, respectively, while NO_3 and pH were rated as good (G-GW) and excellent (E) for drinking uses depending on the GW.Q.I. values of 99.4 and 17.8, respectively. The average value of the GW.Q.I. for the selected wells was 177, and the groundwater quality in Al-Hillah city was rated as poor for drinking uses.

3.3 Producing of Distribution Map of Groundwater for Drinking Uses

For Al-Hillah city, the distribution map of groundwater for drinking uses using the GW.Q.I. method can be seen in Fig. 5. Then, based on the GW.Q.I. values, Fig. 6 shows the distribution map of groundwater rating for drinking.

Areas and their proportions of GW.Q.I. and GW.Q.R. in Al-Hillah city that resulted from Figs. 5 and 6 can be seen in Table 7. The values of valid areas that can be used for drinking and other uses cover 126.8 km^2 (14.75%) of the entire area of Al-Hillah city 860 km^2, which were rated as excellent and good. Otherwise, about 7% of the total areas were

Table 6 Values of the GW.Q.I. for drinking uses for each variable and its rating

Variables	GW.Q.I	GW.Q.R
Na	553.2	Vc-GW
TDS	1207.7	Vc-GW
EC	867.6	Vc-GW
CL	579.8	Vc-GW
HCO_3	176.2	P-GW
SO_4	692.9	Vc-GW
Ca	446.4	Vc-GW
Mg	462.1	Vc-GW
NO_3	99.4	G-GW
K	118.2	P-GW
PH	17.8	E-GW
Average	**177**	**P-GW**

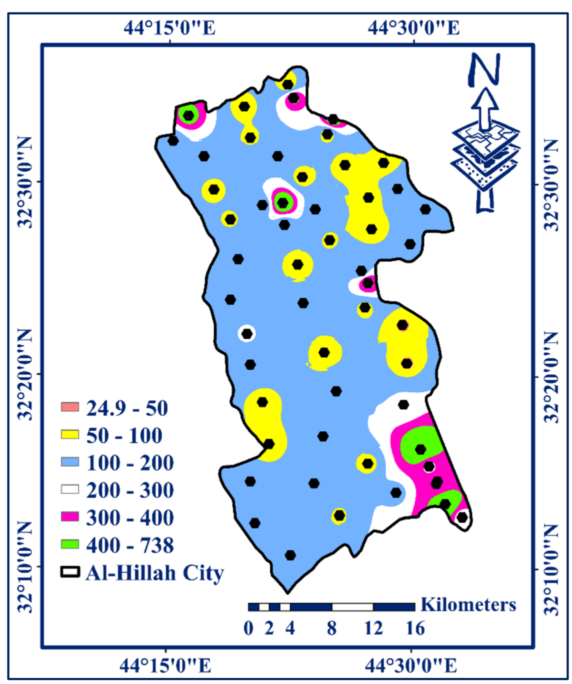

Fig. 5 Distributing map of GW.Q.I. for drinking uses of the Al-Hillah city, Babylon, Iraq

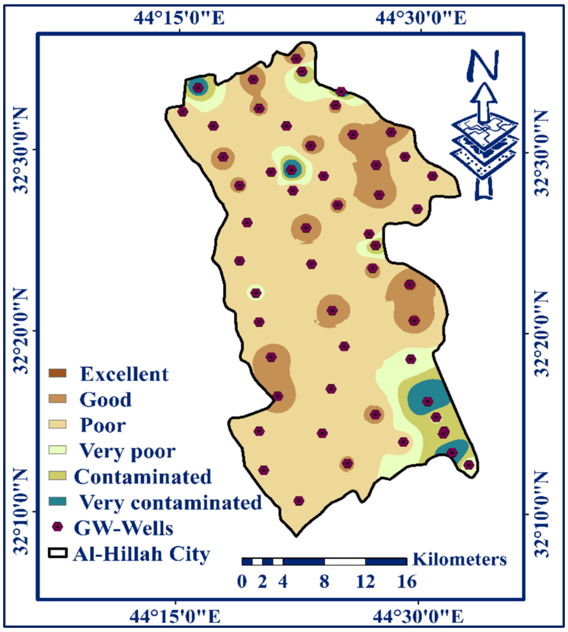

Fig. 6 Distributing map of GW.Q.R. for drinking uses in the Al-Hillah city, Iraq

Table 7 Areas and their proportions of GW.Q.I. and GW.Q.R. in Al-Hillah city

Value of GW.Q.I	GW.Q.R	Area (km^2)	Area %
24.9–50	E-GW	5.1	0.60
50–100	G-GW	121.7	14.15
100–200	P-GW	609.9	70.92
200–300	Vp-GW	63.4	7.37
300–400	C-GW	35.9	4.17
> 400	Vc-GW	24.0	2.79

considered unacceptable for drinking uses, rated as contaminated and very contaminated.

4 Conclusion

This study has been set to rate the groundwater quality for drinking uses. It is interesting to study the groundwater employed to use in several daily uses that will be extracted from wells distributed in different areas in Al-Hillah city. Therefore, the groundwater quality index model was applied to determine groundwater quality and its suitability for drinking before use by humans. A comparison has been done for the groundwater in the study area with the local groundwater and international standards.

The distribution maps for groundwater have been established using the groundwater quality index for drinking uses and entered into the GIS for this purpose. The produced maps will ease researchers and scientists to determine the quality of groundwater and help them know its ranges and distribution in the study area. The IDW method and the GIS were combined to produce interpolation maps for groundwater quality for drinking uses using twelve variables measured in 56 wells within Al-Hillah city.

The twelve variables entered in the weighted arithmetic method to calculate the groundwater quality index for drinking uses are Ca, Mg, Na, k, C, SO_4, HCO_3, TH, TDS, NO_3, and EC. Based on the GW.Q.I. values, the generated map of groundwater quality was rated into six categories ranging from excellent to very contaminated.

For each variable, the prediction map was produced as a distribution map to cover the whole study area by using the prediction method IDW as a tool existing in the GIS.

The results showed that the generated map for the groundwater quality index in Al-Hillah city was classified and rated into six categories for drinking uses. These categories were occupied (in km^2) 5.1, 121.7, 609.9, 63.4, 35.9, and 24.0 km^2 with a rating of excellent, good, poor, very poor, contaminated, and very contaminated, respectively. For the selected wells, the average value of the groundwater quality index for drinking uses in Al-Hillah city was about 177; consequently, it was classified as poor water (P-GW) for drinking uses.

In general, the new map of the groundwater classification is significant for future works. These maps provide valuable information on the groundwater status at each well in the study area using some physical and chemical variables. It can be a new guide for academic, agricultural, and industrial specialists.

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Data Availability All data are included within the text.

Declarations

Conflict of Interest The authors declare no competing interests.

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