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Implementation of the Quality and Creating GIS Maps for Groundwater in Babylon, Iraq

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ABSTRACT

In times of water scarcity, groundwater is a vital resource that provides an alternate source of water for human consumption. In Iraq, the quality of rivers has been greatly affected by climate change and the dwindling availability of surface water. Examining and classifying the groundwater in this region is now vital. The present study sought to incorporate the groundwater property data (drinking purpose) with a geographic information system (GIS). Eleven variables were measured in 25 wells to investigate the physio-chemical properties around the Babylon province of Iraq. On the basis of the acceptability of groundwater for drinking, GWQI was categorized into four primary groups in the results. Approximately 28% of the twenty-five wells (1811.04 km^2) are of excellent quality, 24% are of good quality (1552.3 km^2), 44% are of low quality (2845.9 km^2), and 4% are extremely contaminated (2587.2 km^2). The average GWQI for the entire study region was 110.7, making it inappropriate for human consumption. It has been determined that approximately 52% of the groundwater from the examined wells can be deemed safe for consumption, although certain measurements surpass the permissible limits. To guarantee that the residents in these areas are supplied with water of superior quality and safety, treatment of the tested groundwater is recommended before use.

Keywords: groundwater quality, wells, quality index, IDW interpolation, GIS.

INTRODUCTION

The effects of population growth, global warming, and increased human activity have caused a drastic drop in water quality, a problem that affects both local and global populations. The Index of Water Quality (WQI) is an indicator of this reality, demonstrating the severity of this issue (Krishan et al., 2016). Using multiple physio-chemical factors, researchers evaluated the WQI for drinking purposes. Multiple aspects must be considered when gauging the quality of water (Gitau et al., 2016). Additionally, the levels of the elements within the water have a substantial impact on the WQI evaluation. Furthermore, analyzing each variable individually does not provide an exhaustive overview of this measurement. Water treatment is necessary when the variables in an area do not exceed standards (Boudreabala, 2017). It is feasible to calculate the WQI for drinking reasons utilizing numerical or mathematical approaches. In the groundwater, using these techniques may provide a comprehensive picture of quality in a particular area quickly and easily, preventing the drilling of wells in the locations where the groundwater is unfit for consumption (Shil et al., 2019).

It is evident that the properties of the water source have a great impact on groundwater quality and suitability for utilization. Continuous monitoring as well as control of chemical and physical parameters are implemented to preserve groundwater quality. Recent water shortages in Iraq have increased because of the global warming, dam development, source of the river, politics, and irrational use of water consumption. Consequently, it was essential to consume groundwater resources in order to address this deficiency. Therefore, a qualitative examination is required to establish its convenience for utilization. The use of GIS to obtain maps of the distribution of wells using pertinent factors might be extremely beneficial. With the aid of these maps, a comparison of water quality across several sites is made possible. For the groundwater, the quality is studied by using the quality index technique, which is the most commonly employed in emerging countries to preserve excellent quality in water. When surface water levels decline, it offers a crucial method of water storage for future usage by countries. Due to its significance as one of Iraq's most vital natural resources, it has become a permanent groundwater study site. This study investigated the suitability of the groundwater in Babylon Province for a variety of applications, primarily construction.

In Babylon Province, fluctuations in groundwater levels and its chemical composition were thoroughly researched. The tests conducted on the groundwater samples suggest that they are unsuitable for human, animal, and industrial consumption. On the basis of irrigation models for the index of the WQ in a GIS context, the groundwater in Babylon province was appraised for irrigation purposes. In Babylon province, 48 wells were analyzed for Ca, Mg, Cl, E.C., HCO_3, Na, and S.A.R. The results indicated that the region was 48.4 km^2 (severely restricted), 399 km^2 (very restricted), 384.3 km^2 (moderately restricted), 28.1 km^2 (lowly restricted), and 0.2 km^2 (not restricted) based on the forecasted maps (Chabuk et al., 2020). Numerous researchers have utilized the WQI approach for evaluating the purity of groundwater in different research locations. Using physicochemical parameters to evaluate and classify the groundwater for Al Najaf city, during 2017 Alikhan et al. (2020).

According to the study, the WQI score was considered low quality. In the camp of refugees (Domiz) in Duhok north Iraq, the WQI approach has been applied to analyze the groundwater. A twenty-four-variable analysis has been conducted on eight wells. Well 1 had extremely low WQI values; wells 2 and 3 had low WQI values; wells 4, 6, and 7 had good WQI values; and wells 5 and 8 had exceptional WQI values (Mohammed et al., 2020). In Erbil city, Iraq, the Canadian model has been applied to examine the groundwater suitability for drinking, municipal purposes, and agricultural activities. In December 2016, March, June, and September 2017, a total of 22 variables were monitored in 16 wells. This study includes pH, E.C., T.H., 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 as independent factors. With a WQI of 38.9, the groundwater quality in the research region was determined to be substandard. Additionally, the study requires an evaluation of groundwater for drinking purposes (Othman and Ibrahim, 2021).

The area of the research does not have comprehensive assessments for the quality of the groundwater. It has been affected by climate changes, necessitating the search for an alternative approach to compensate for the shortfall. WQI will be a valuable resource for researchers and specialists. In addition, the governorate's future objectives include acquiring new supplies of potable water as necessary and supporting the construction of future suburbs. Additionally, WQI is a good technique for illustrating groundwater to the general public. The purpose of the study was to investigate the groundwater acceptability in Babylon Province for domestic and human needs purposes by measuring the variables present in 25 wells in various locations. The WQI model will be created using groundwater for consumption (GWQI). IDW interpolation is used to enter the groundwater quality index values into the GIS.

MATERIAL AND METHODS

Study area

Babylon province is a part of Iraq and is located between 32° 32' 31.91" North and 44°25' 17.17" East. Al-Hilla city is the capital of it. It consists of four main districts: Al-Hilla District, Al-Hashimiya District, Al-Mahawil District, and Al-Musayab District, as shown in figure 1. It is located in a dry zone and has 6,468 square kilometers an area. The average thickness of this city's soil is 20 meters. Its main soil types are "sandy loam, loamy sand, and silty clay", and it is located in the Mesopotamia plain zone. Groundwater ranges from 0.4 to 4.5 meters deep (Mahmoud et al., 2021). The direction of the groundwater flow is from northwest to southeast open-channel drainage (Al-Madhlom et al., 2020). Figure 2 presents the selected locations for 25 wells around Babylon Province, which will help to obtain a comprehensive view of the study aims. All the wells were used for sampling to show the suitability of groundwater for drinking.

Data collection and analysis

Figure 2 shows a map of 25 locations where well water samples have been collected. Wells utilized for drinking water, farming, and other domestic and commercial uses were chosen for the sample. Before collecting water samples in a polypropylene container, the container was rinsed numerous times with water. Outside, water samples are stored in a cooler, while in the laboratory; a refrigerator is maintained at 2 to 4 degrees. Throughout the sampling and processing of the materials, all necessary steps were taken to prevent contamination. In addition to EC and pH, numerous other variables, including Ca^{+2}, HCO^{-3}, NO^{-3}, Cl^{-}, K^{+}, Mg^{+2}, Na^{+}, SO_4; and TDS, were evaluated. Below are the key characteristics of each parameter:

1) the pH level of a substance, which measures the number of hydrogen ions in water, determines whether it is acidic, neutral, or basic. The pH levels in water (drinking) must be from 6.5 to 8.5 (Agrawal et al., 2021).
2) calcium is a mineral that can cause gastrointestinal issues when the concentration is high. Its presence in high concentrations is not recommended for household use, because it can cause scaling and encrustation.
3) those who are allergic to high chloride levels may feel laxative symptoms, and high chloride levels in water have a salty flavor. In water, excessive chloride levels might be dangerous.
4) owing to the physical origins of fluoride in the ground, the local water has a minor quantity of fluoride. Fluoride helps prevent tooth decay at very low doses; however, greater quantities can lead to fluorosis in people (Dandge and Patil, 2022).
5) the calcium and divalent magnesium ions are responsible for hardness in groundwater. The concentration of these ions is largely determined by the soil and rock formations in the area and is seen most frequently in locations. The upper layer of soil is thick and limestone rock texture are present.
6) magnesium is one of the significant minerals for the human body's health. It helps keep bones strong and healthy. Hard water that has high quantities of calcium or magnesium is not suitable for daily consumption.
7) the health of people can be seriously endangered by high nitrate levels in water for drinking use and public water sources, as they can cause thyroid disease, diabetes, cancer of the stomach, and methemoglobinemia (Kumar et al., 2015). Agrawal et al. (2021) noted the value of nitrate in water above 45 mg/l and determined that human activity is the main contributor.

GIS was used to forecast the concentration of each parameter in each well during analysis.

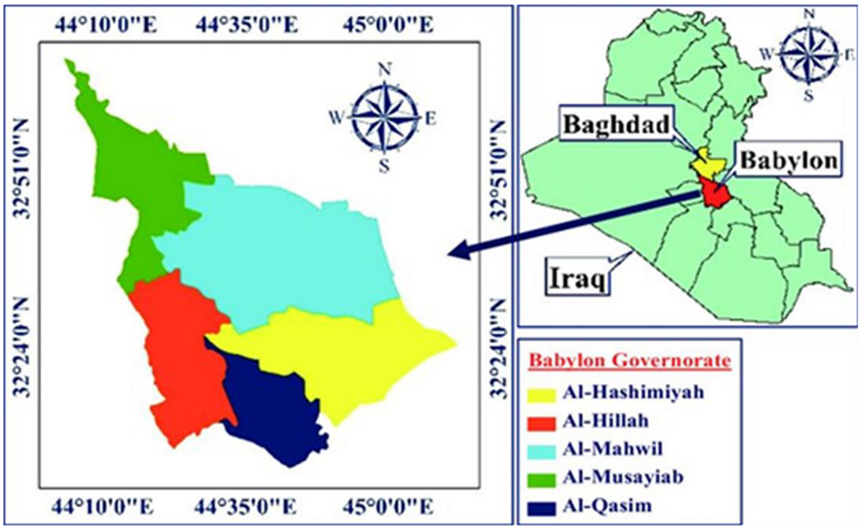

Figure 1. Map of Iraq and the location of Babylon Province

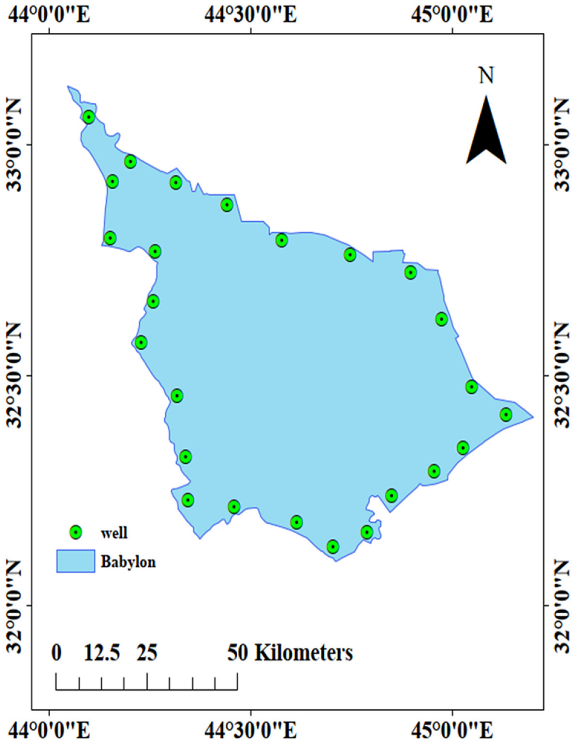

Figure 2. Map of the study area showing the sampling sites

Using a portable GPS device, the latitude and longitude of collecting sites have been determined. The various locations were uploaded as a point layer into GIS software. Also, each point in the point attribute data table was given a special code. In the data table, different columns included values for all chemical parameters. ArcGIS software version 10.0 has been used to produce maps of various water parameters by using a geodatabase. The spatial analyst module has been utilized to create a distribution for the GW quality (drinking uses) contaminants using the inverse distance weighted raster interpolation technique.

Calculation of WQI

WQI is a signal for monitoring with controlling groundwater quality (Bora and Goswami, 2017). It aggregates a bulk of information on water quality into a single value that reflects the whole picture. Algorithms that may or may not employ water quality criteria are just one of many possible approaches to calculating the WQI. (WHO, 2017). The GWQI (drinking uses) in Babylon Province was computed by applying the weighted arithmetic method. The process entails giving the components of water quality a weighting factor, then adding the resulting values by a geometric mean. Twenty-five wells across town are used to compile the index. The GWQI for drinking at wells in Babylon province is used in the following equations (Alsaqqar et al., 2015):

$$Si = \frac{C_i - C_0}{ST_i - C_0} \times 10 \tag{1}$$

$$IWi = \frac{1}{ST_i} \tag{2}$$

$$GWQI = \frac{\sum ST_i \times IW_i}{\sum IW_i} \tag{3}$$

where: *Si* – sub-index of (i) variable, *IWi* – the inverse weight for the standard value (*Vi*) of (*i*) variable, *STi* – standard value (*i*) variable, *Ci* – the obtained concentration value for (*i*) variable, *Co* – the optimal value for each water-related variable (WHO, 2017).

According to the GWQI category, the rating of WQ (GWQR) has assigned to each well in Babylon Province. Each well has been assigned a GWQR based on its GWQI category. (Alsaqqar et al., 2015; Ali, 2017). Figure 3 illustrates the classification of groundwater based on the WQI. There are six categories in this model to show the WQ depending on WQI (Reyes et al., 2020; Makki et al., 2021). Figure 4 illustrates the calculation process for the GWQI drinking water quality index. The value of each variable was tested in 25 wells in Babylon Province, Iraq (Tripathi and Singal., 2019; Akhtar et al., 2021). Table 1 shows the measured concentrations of the significant WQ-affecting parameters. Morever, Table 2 shows the calculation procedures for the GWQI for the measured concentrations in Table 1. Using data from 25 wells all over the research area, ArcGIS was used to create the necessary database for

GW.Q.I. < 50	• Excellent (E-GW)
50 < GW.Q.I. < 100	• Good (G-GW)
100 < GW.Q.I. < 200	• Poor (P-GW)
200 < GW.Q.I. < 300	• Very poor (Vp-GW)
300 < GW.Q.I .< 400	• Contaminated (C-GW)
GW.Q.I. > 400	• Very contaminated (Vc-GW)

Figure 3. GWQR classification of groundwater based on GWQI values (Makki et al., 2021)

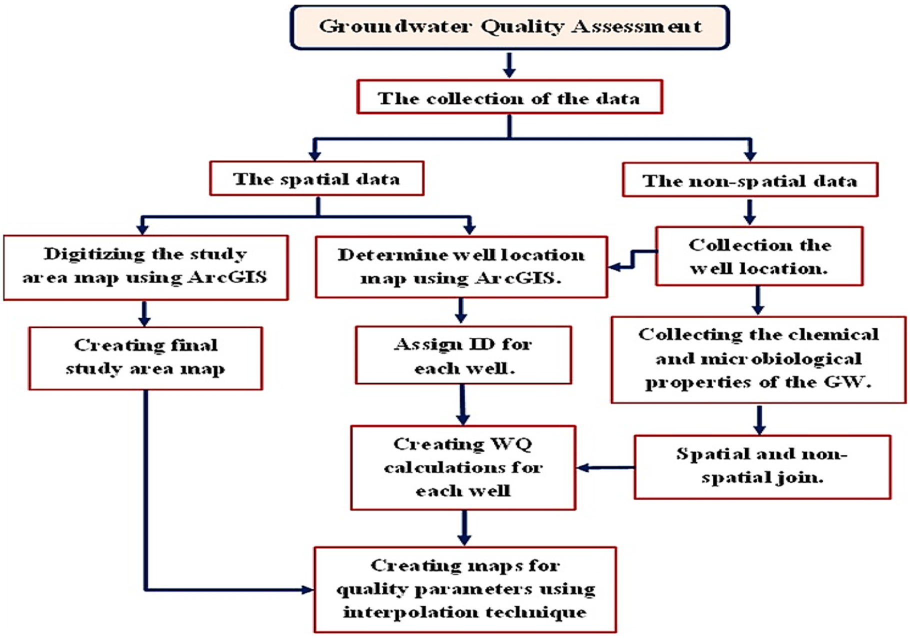

Figure 4. The flow chart of the method (Sutadian et al., 2016)

Table 1. The measured variables in 25 wells

Well	Na	TDS	EC	Cl	HCO_3	SO_4	Ca	Mg	NO_3	K	pH
W1	315	2400	3103	512	262	710	154	232	1	0	6.8
W2	410	15890	25,205	2943	935	7882	812	460	4	12	7.6
W3	173	886	1342	257	124	257	128	75	1	2	6.2
W4	609	3453	5296	1031	112	1260	198	195	12	0	8.2
W5	163	1324	2042	349	122	267	188	72	1	4	6.6
W6	212	1200	1902	372	392	240	100	90	0	0	7.5
W7	3110	8175	6602	1067	246	2562	240	399	9	0	7.7
W8	2890	735	1207	139	477	74	122	67	0	0	7.2
W9	2540	8136	3302	680	267	389	227	145	9	4	6.1
W10	41	480	752	87	222	130	94	52	11	0	7.7
W11	166	8030	1334	185	124	336	59	32	3	2	7
W12	159	821	1252	246	118	253	128	72	1	2	7.2
W13	244	1678	2502	262	211	533	147	60	2	1	6.2
W14	9610	22100	20,602	1848	618	5770	513	315	6	10	6.1
W15	256	1885	3633	313	210	595	160	70	1	1	8
W16	644	8529	5707	961	246	2026	170	399	5	0	7.7
W17	152	1005	1525	300	197	219	170	72	2	4	6.2
W18	388	8437	8502	2024	592	1258	146	370	1	0	7
W19	133	681	1032	192	90	218	114	56	1	1	7.2
W20	2150	25000	1859	232	154	389	88	54	1	1	7.8
W21	149	758	1182	229	118	223	129	62	1	2	7
W22	143	1050	1607	144	124	336	39	31	0	1	7.3
W23	196	1507	20529	189	117	504	141	54	3	1	7.4
W24	2300	18200	12302	3200	182	382	360	220	1	8	6.7
W25	3100	700	1081	132	462	100	90	90	15	0	6.9
Aver	1210	5722	5416	716	269	1077	189	150	3.6	2.2	7.09
SD	2013	7086	6760	857	201	1820	159	132	4.2	3.2	0.61
WHO 2017	200	500	1000	250	200	250	75	50	10	12	7.5

Table 2. The steps of the GWQI calculations

Variables	C_i	C_o	ST_i	IW_i	Si	$IWi \times Si$	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

groundwater that can be used for drinking. With these databases, the spatial distribution of all parameters was then mapped, and the results will be shown and talked about. These maps accurately assess GWQ and determine the capability of a well for extraction with a fewest errors.

RESULTS AND DISCUSSION

The predicted maps by GIS

The distribution maps of the physical and chemical parameters are illustrated in Figure 5. In Figure 5a, the Na concentration was extremely high in one of the 25 wells, with a range of 8400 to 11000 ppm. In addition, six of the twenty-five wells fell into the second category, which ranges from 2100 to 4200 ppm. The map depicts 43 wells with a Na concentration between 40 and 2100 ppm. The Na results indicate that seven wells, or 14% of all wells, have a higher concentration than others. Furthermore, the map illustrates the distribution of Ca, as shown in Figure 5b. In 24 wells, the Ca distribution in Figure 5b ranges from 20 to 600 ppm. The Mg distribution in the majority of the 25 wells has been between 10 and 360 ppm (Figure 5c). In Figure 5d, the K distribution map shows all the low-range wells (0–40 ppm). The low values of K indicate that this parameter has little impact on water quality. Due to the distinct negative effects of sodium on the physical characteristics of soil, the peril posed by salt is given special consideration. The salt absorption ratio (SAR), which assesses sodium risk, is frequently employed. SAR calculates the ratio of Na to Ca and Mg ions in the sample of the water. The effects of the high salt levels in drinking water on humans and other animals are significant. Additionally, this will restrict aeration and decrease water access in the soil profile and on the soil surface, slowing crop growth. Human activity and the rocks with soil are the two primary sources of cations in groundwater. They reach groundwater by filtering water through the sediment (Aly et al., 2015). The map's distribution reveals that cation concentrations are highest in the northeast and diminish toward the west and south.

Figure 6 illustrates the variation in EC, TDS, Cl, and pH across the 25 wells. In the majority of wells, the EC was from 620 to 9500 mhos/cm, as illustrated in Figure 6a. The EC of water shows the measurement of its capacity to discharge an current. Salts and other substances may dissolve in water to form positive and negative ions. Because these unbound ions conduct electricity, the concentration of ions affects the electrical conductivity of water. Consequently, this can serve as an indicator of ion effects.

Figure 6b additionally depicts the distribution of total dissolved solids (TDS). The map shows that the TDS of one well falls within the range of 24,000 to 32,000 ppm. However, the TDS concentrations of the other wells are lower, which may contribute to results that meet the requirements of the WHO. In terms of both quantity and variety, liquids comprise a vast array of dissolved and undissolved substances. Higher solids content waters have laxative effects and occasionally have the opposite effect on the persons whose bodies are not acclimated to them. TDS is made up of wastes that require oxygen to break down and pathogens that can have a significant negative impact on public health. In addition, Figure 6c

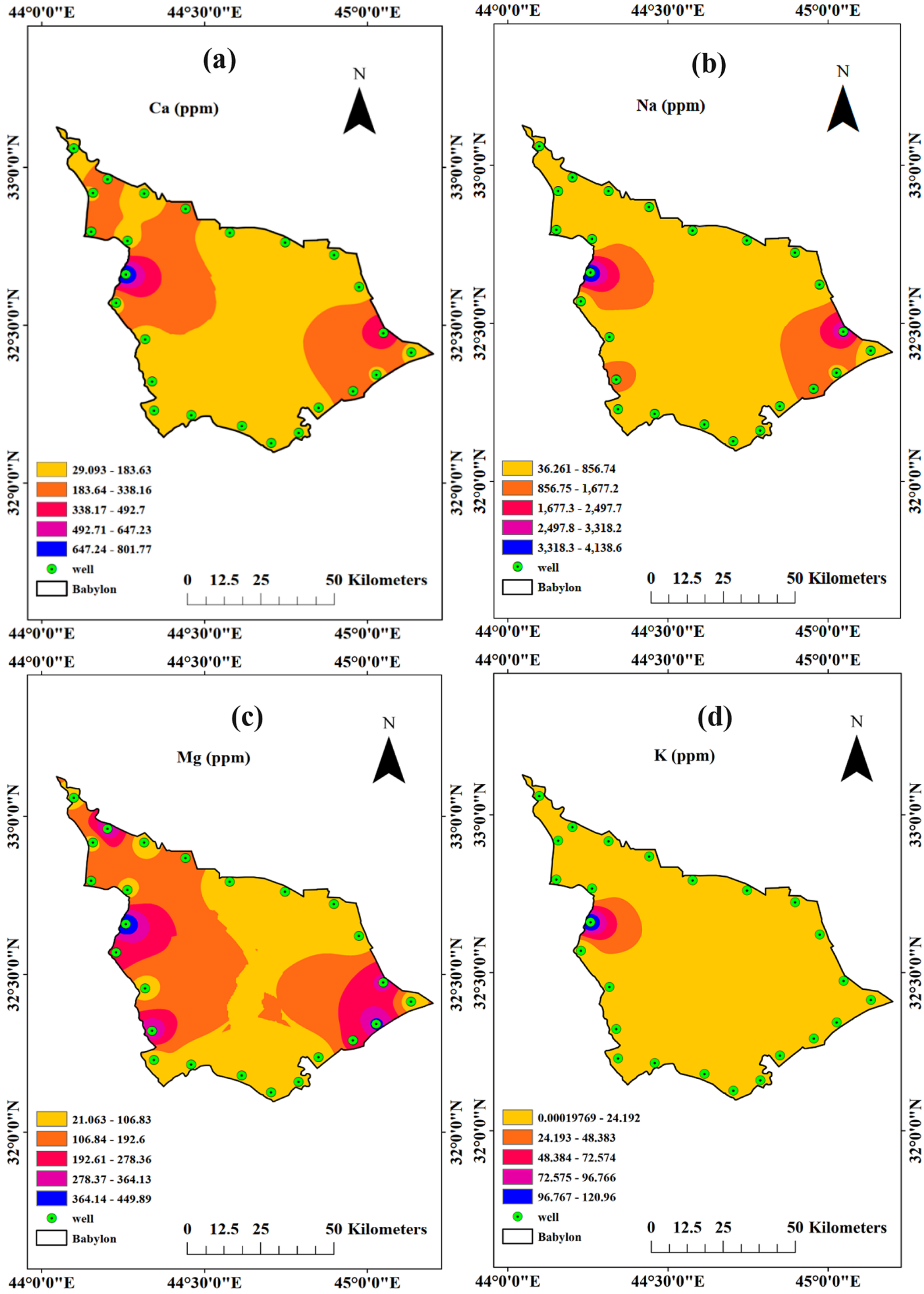

Figure 5. The distribution map of (a) Na, (b) Ca, (c) Mg, and (d) K

illustrates the Cl distribution throughout the study area. The concentrations of Cl range from 40 to 2900 ppm in the majority of the 25 wells. The majority of concerns stem from the well-known relationship between high chloride and high sodium levels. Chloride in drinking water is not hazardous. Some disorders may have elevated chloride concentrations as a primary cause. In 24 wells, the pH distribution in the location of the study falls within the first two categories of the range, which are 6 to 7 and 7 to 8. As shown in Figure 6d, one well has a pH within the range of 8 to 9, indicating that it is acidic. At a pH level of 8.5, the taste of the water may become harsher. This alkaline pH may also contribute to the buildup of calcium and magnesium carbonate in pipelines.

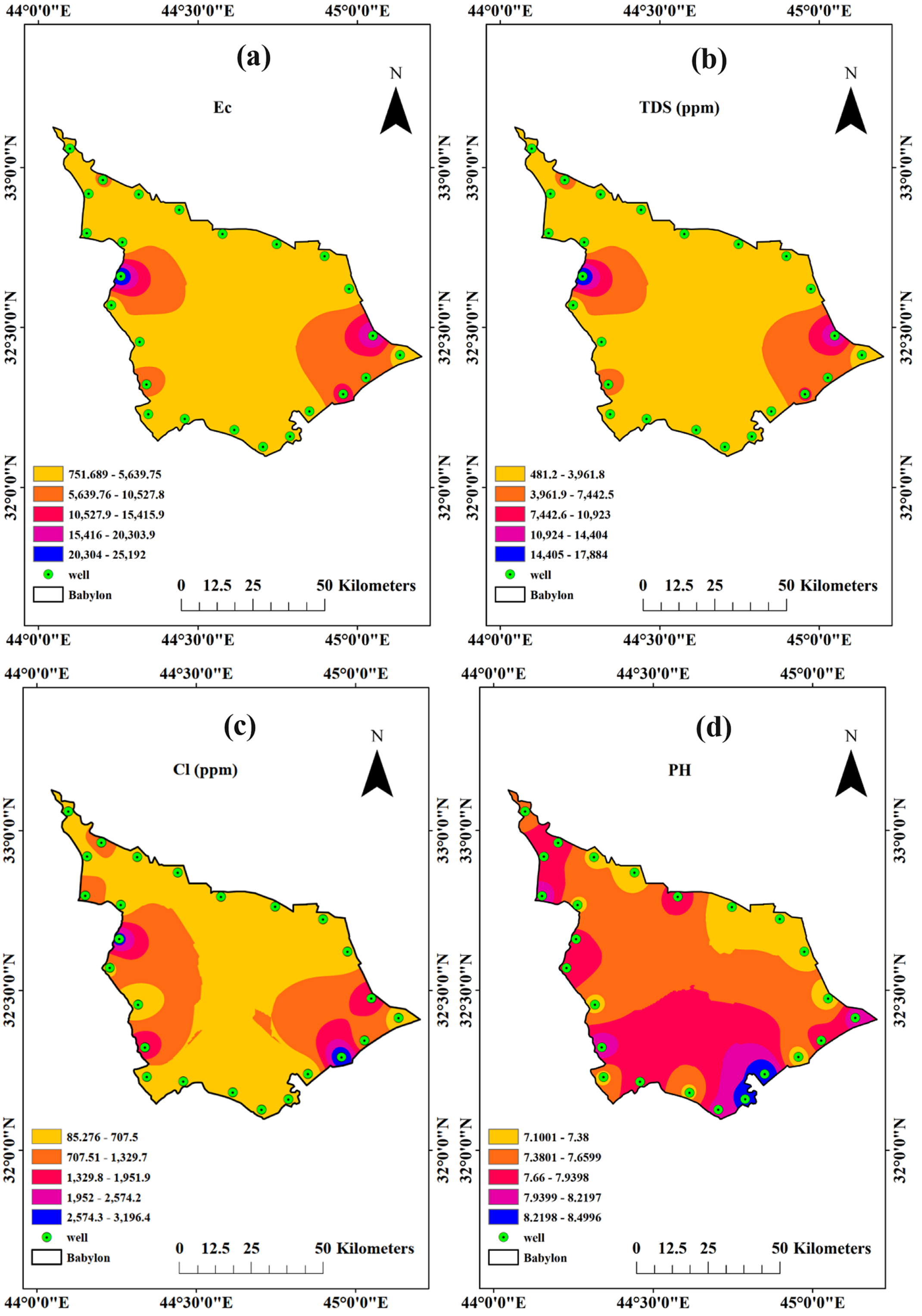

Figure 6. The distribution map of (a) EC, (b) TDS, (c) CL, and (d) PH

Figure 7 shows the variations in NO_3, HCO_3, and SO_4 in the study area. The interpolation map readings for NO_3 range from 0 to 42 ppm. The values fall within the low range, as shown in Figure 7a. Everyone in the household should consume water with nitrate concentrations (measured as nitrate-nitrogen) below 10 mg/L. The U.S. Environmental Protection Agency's drinking water regulation for public water supplies is 10 mg/L of nitrate. The primary alkaline component in practically all water is HCO3, the bicarbonate ion. Alkalinity acts as a buffer to mitigate acids.

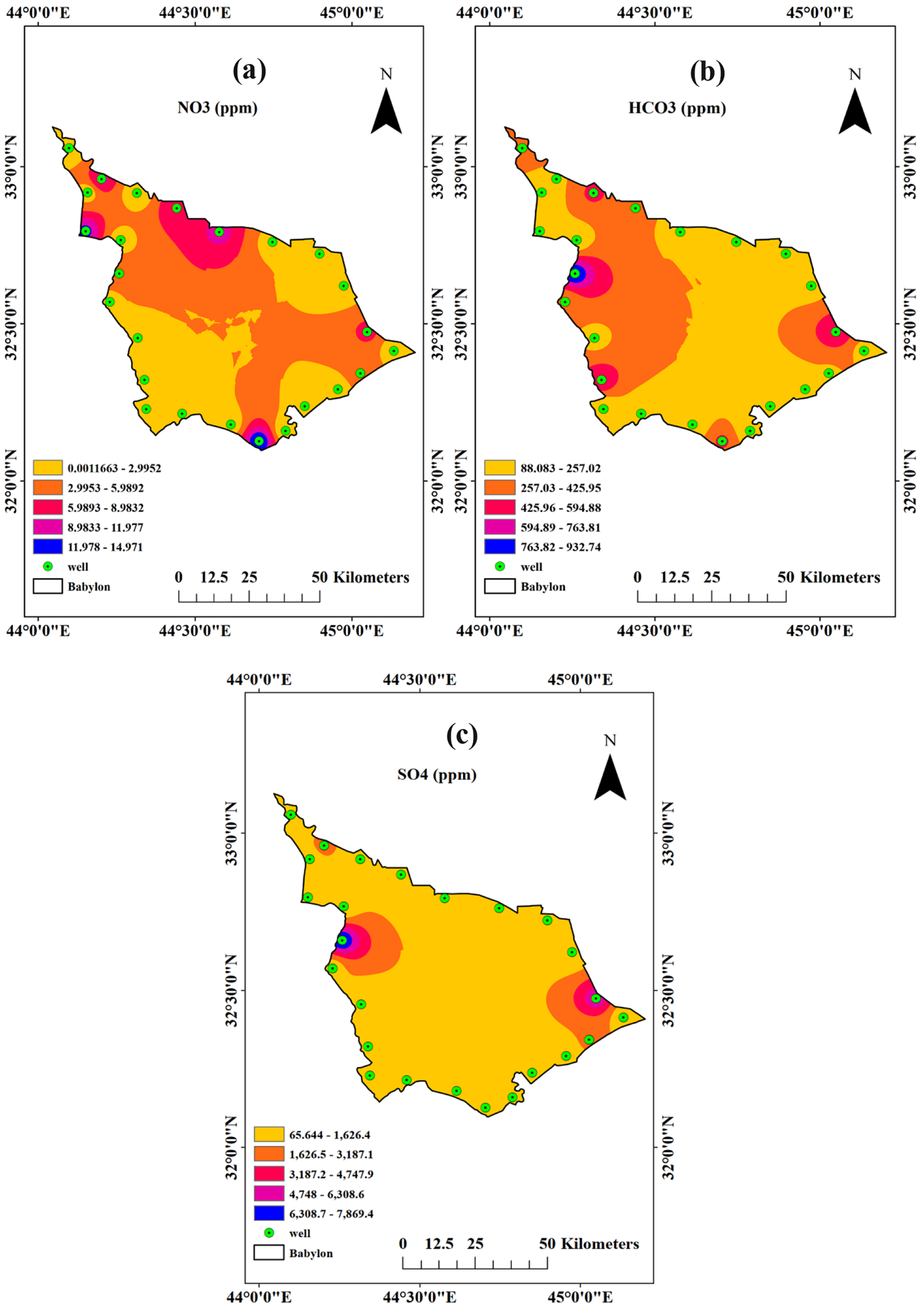

Figure 7. The distribution map of (a) NO_3, (b) HCO_3, and (c) SO_4

In addition, Figure 7b shows that the majority of wells have the HCO_3 concentrations within the range of 80 to 400 ppm. Generally, it is of little consequence; however, it can be a concern in certain industries, such as those dealing with beverages, cooling towers, boilers, and textiles. Furthermore, Figure 7c illustrates the distribution and variation of SO_4 in the study region. One of the twenty-five wells has a reading between 6200 and 8600, which is a high value. The majority of the other wells have low ranges. The criteria for the secondary maximum contaminant level

Table 3. GW.Q.I. Classification for drinking applications; variable values within the permitted range

Well	GW.Q.I.	GW.Q.R.	Well	GW.Q.I.	GW.Q.R.	Well	GW.Q.I.	GW.Q.R.
W1	115.9	P-GW	W10	93.3	G-GW	W18	168.0	P-GW
W2	471.7	Vc-GW	W11	21.8	E-GW	W19	42.7	E-GW
W3	47.3	E-GW	W12	48.8	E-GW	W20	85.9	G-GW
W4	171.7	P-GW	W13	43.4	E-GW	W21	45.1	E-GW
W5	83.4	G-GW	W14	186.5	P-GW	W22	110.9	P-GW
W6	64.7	G-GW	W15	109.8	P-GW	W23	131.1	P-GW
W7	168.2	P-GW	W16	152.2	P-GW	W24	112.0	P-GW
W8	39.1	E-GW	W17	53.7	G-GW	W25	121.1	P-GW
W9	81.9	G-GW				Average	110.7	P-GW

Note: E-GW – excellent groundwater; G-GW – good groundwater; P-GW – poor groundwater; Vc-GW – very contaminated groundwater.

(SMCL) include sulfate. SMCL for potable water is 250 ppm of sulfate.

Groundwater quality index (GWQI)

GWQI is presented in Table 3 and Figure 8. In Babylon province, the average GWQI value for the wells is 110.7, indicating that the water quality is subpar. Figure 8 shows that approximately 44% of the study zone is classified as PGW (poor) and 4% as VPGW (very poor groundwater). In addition, the water quality is EGW (excellent groundwater) at 28% and GGW (good groundwater) at 24%. The GWQI in 14 wells is unsuitable for human consumption, as shown in Table 3. High values of Ec and Cl in the GW of wells are the primary causes of the decline of GW quality. According to previous research, groundwater flows in the study region from the west side to the east side and from the southeast side to the northeast side (Eslami et al., 2017; Banda and Kumarasamy, 2020). Dissolved rocks with various chemical compositions contaminate groundwater to a greater extent due to the distance traveled before reaching the wells that were analyzed. Another factor contributing to decreasing the WQI values and the drop of its character is the constant withdrawal of water to meet human needs.

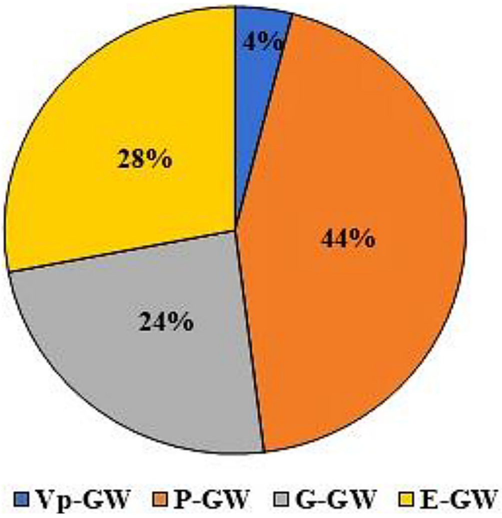

Figure 8. The percentage of GW.Q.I. in the study area

CONCLUSIONS

The current study goal was to explore whether or not GW is suitable for human consumption. The possible uses of groundwater pumped from wells located in various parts of Babylon Province make it an intriguing topic for research. Because of this, GWQI was used to assess the purity of the groundwater and its suitability for human consumption. Various international and local GW standards have been compared with the GW in the study region. The evaluation of GW for consumption purposes was conducted utilizing the GWQI, and the data was entered into GIS for the same reason.

WQI and GIS will make it easier for experts and professionals to evaluate the quality of groundwater and find out where it is in the research region. Utilizing the Inverse Distance Weighted (IDW) with GIS, samples from 12 variables taken from 25 wells in the Babylon province were used to make interpolation maps of the GWQ (drinking uses). The Ca, Mg, Na, K, Cl, SO_4, HCO_3, TDS, NO_3, pH, and Ec parameters have been utilized to determine the GW potable WQI. According to the GWQI values, GWQ was divided into 6 groups ranging from excellent to very poor. As a method of prediction, the data were analyzed in wells for each variable using the IDW tool in GIS. According to the results, the groundwater quality index map for Babylon province was classified and ranked into four categories. The area occupied by each of these categories (in km^2) is 1811.04, 1552.3, 2845.9, and 2587.2 for scores of excellent, good, poor, and very polluted, respectively.

The mean GWQI for drinking uses in Babylon province for the sampled wells was 110.7; therefore, the GW was deemed unsuitable for human consumption. (Poor). In general, the GW GIS colored map will be crucial in the future. These maps provide beneficial information regarding the groundwater conditions at every well in the research area, based on certain physicochemical parameters. It is useful for academics, agricultural specialists, and industry professionals. The WQI readings indicate that extra steps are needed to raise the quality of the groundwater in the analyzed wells so that it may be used for drinking. After performing the appropriate treatments to make sure that the soil and plants are not harmed, it is preferred to utilize the on-site drinking supply, represented by groundwater in the investigated region. This action helps ensure the sustainability of water resources and the conservation of freshwater. Financial assistance for groundwater extraction and quality control is one of several obstacles that government agencies must overcome in order to execute new laws. There are also issues at the societal level, where the government must organize education programs to spread the necessary social awareness if the local population is to cooperate in implementing new practices. The majority of nations in the world have sufficient understanding of and experience managing groundwater. Future government policies might include best practices from other parts of the globe where GW harvesting is properly managed.

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