Article

Monitoring and Evaluation of Water Quality in Underground Aquifers Using (GIS) and (IWQI): Western Karbala's as a Case Study

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Abstract: This study assesses the current state of groundwater quality and provides a combination of water quality criteria that may be utilised to develop the irrigation water quality index (IWQI), a suitable technique for classifying irrigation water. Seven wells' worth of water were collected in the region under evaluation, and their physical and chemical characteristics, such as cation and anion concentrations, were examined. One of the interpolation methods, namely "Inverse Distance Weighted (IDW)", was employed in a geographic information system (GIS) to analyse the data obtained. The water may be labelled as "severe restriction, SR" because the projected values of the irrigation water quality index (IWQI) were more than zero but less than 40. Throughout the six-year period (2017, 2018, 2019, 2020, 2021, and 2022), water samples from seven wells in the studied area have been analysed for their major and minor components. The finding shows that the irrigation water quality indexes (IWQIs) for 2017 and 2018 had measured values above zero but below 55, whereas IWQIs for the other years had calculated values below 40. Therefore, the water can be identified as "High Restriction (HR)" in the early years and as "severe restriction (SR)" in the latter years. Consequently, this water cannot be utilised for irrigation, and it is abundantly evident that there will be a shortfall in the value of IWQI for a number of years in a row.

Keywords: Water quality index; Irrigation; Groundwater.

1. Introduction

Water is a crucial natural resource since it is essential to all life forms, indicates the way life will go on for all species, and is a major powerhouse for the whole planet. More than 2,000,000,000 people depend on aquifers for their primary water source, and groundwater could be used to irrigate 40% of the world's crop area. Among the several sources of water, groundwater is crucial [1]. Aquifers are underground water supplies that arise when rainwater or snowmelt seeps downward through the earth and into the spaces between soil particles and rock. Bear J. and Ilkhchi R. defined an aquifer as a geological formation that can store and transmit large volumes of water under normal field conditions [2,3]. The basic objectives of water quality evaluation for irrigation are to decide if the water is suitable for use in agricultural irrigation, characterise the water quality on regional or national scales, and analyse the changes in quality over time [2].

Traditional methods are necessary for assessing water quality because they compare measured values with acceptable criteria. The use of such a strategy is useful for identifying potential sources of constraint; nevertheless, it will not provide a holistic picture of the temporal and geographical evolution of the total water supply [4,5]. The use of indices, which combine information from several sources into a single value, is one approach to describing water quality. With this strategy, it's less of a stretch to articulate the myriads of pieces of evidence that go in this direction [6,7]. Water quality indicators are a straightforward and easy-to-understand method for identifying the quality of water and its optimal usage in the irrigation industry. It is common for the salinity of water to increase gradually within a flow domain, even if the domain only consists of a single layer. This is because groundwater migrates between discharge and recharge zones, which results in the dissolving of the water's salt content. Iraq's geological environment makes it possible for the country to have a quality profile with a sedimentary layer that ranges in thickness from 4 to 13 kilometres. Iraq has a high-quality profile, which makes this achievable.

Previous research has applied WQI with or without the use of GIS to evaluate and manage the quality of groundwater for various purposes, including household, irrigation, and other applications. This index is an important indicator and is regarded as one of the most active instruments for transferring the specifics of water resource information to decision-makers. Several studies were conducted for Karbala City, Iraq; for example, Mohammed [8] investigated the groundwater quality in the Dibdiba Aquifer and its suitability for human use by applying the WQI and found the water was heavily polluted and unsuitable for drinking purposes. Similarly, Khalaf et al. [9] investigated the suitability for drinking and irrigation purposes of the Al-Dammam aquifer in the west and south-west zones using a WQI map created by the ArcGIS Spatial Analyst tool. Jazeerat Al Najaf's groundwater quality was also extensively discussed using WQI calculations by Alikhan HA et al. [10].

The traditional methods of assessing water quality depend on comparing experimentally calculated parameter values with standard values. These traditional assessment processes simply express a series of parameters in a single value to facilitate the interpretations of broad lists of variables/indicators underlying water quality classification. Generally, the traditional methods properly identify the sources of the limitations; however, they do not readily provide overall views of the spatial and temporal trends in the overall water quality [2].

The purpose of this study is to provide a practical examination into the quality of groundwater in the Karbala desert and how far it is used to meet the appropriate consumption requirements in the development of more green areas. Furthermore, the effort intends to provide a database for other disciplines by graphing the geographical distribution of water quality parameters such as cation and anion concentrations with irrigation water quality index (IWQI) using GIS and the IDW interpolation technique.

2. Study area

Several samples of groundwater were taken at a place 19 km western south of the centre of the Karbala Governorate, in the south of Al-Razzaza lake in Iraq, in order to determine its qualities. The location has a gross area of 2000 dunam and is located at (43°52′44″N) and (32°43′23″E) see (Figure 1). Sediments of gravel, sand, and gravelly sand with the presence of clayey lenses make up the primary aquifer soil type in this region [11,12]. Compacted clay balls with a trace amount of sand and gypsum serve as the agent material for these lenses. The topography in this area is very flat, with a height that varies from 20 to 61 m above sea level (as shown in Figure 2). This map demonstrates how the land drops off sharply from northeast to south-west.

This region is characterised geologically as containing a plain-like to somewhat hilly nature, and it constituted a portion of the Karbala-Najaf plateau, which is located in the middle of Iraq and is part of the Mesopotamia zone [13,14]. The following formations may be found in the stratigraphic column for the area under examination. They are listed in order from most ancient to most recent [15, 16]:

a) Cretaceous Tayarat formation: It is made up of clayey, limestone, dolostone, and dolomitic limestone. This formation is distinguished by the presence of cavities and Karstification in the majority of locations [17,18]. This is the most significant formation during the upper chalky era of sedimentation, which covers a large region of the western desert.

b) The Upper Paleocene Umm Er Radhuma formation: It is composed primarily of dolomite and dolomitic limestone with minor amounts of gypsum and anhydrite. This formation is recognised as an excellent water-carrying formation in the Southern Desert because of the prevalence of cracks, fissures, and cavities [19,20]. Due to the hydraulic connections between the Dammam formation and it, it is a complicated hydrogeological unit [21–23].

c) Dammam formation (Eocene): It's the largest and most significant aquifer in the region around the south-west of Iraq. Dolomite, dolomitic limestone, and limestone are all present in this formation as carbonate rocks. As the investigation progressed, the researchers found that this formation had the highest levels of hydraulic conductivity and transmissivity due to the high concentration of cavities, fractures, karstified canals, fissures, and continuous joints. This conclusion was reached as a result of the fact that this formation had the highest levels of hydraulic conductivity and transmissivity.

d) Euphrates formation (Early Miocene): It is part of the early Miocene series and is one of the most pervasive formations in Iraq. Limestone in this formation ranges from olitic to chalky, sometimes including corals and shell coquinas.

e) Nfayil formation (Middle Miocene): It is composed mostly of green, reddish in parts sandy, dolomitic, and gypseous marl with interbedded calcareous, sandy claystone, and fossiliferous limestone. Gypsum can be found in the form of selenite veins and crystals within rocks.

f) Fat'ha formation (Middle Miocene): It is among Iraq's most commercially significant and widely distributed structures from an aerial perspective. This formation has taken shape in the direction of the south and along the eastern bank of Al-Razzaza Lake. It is made up of a lenticular succession of brownish coarse-grained sandstone, sandy calcareous claystone, and reddish calcareous claystone, with intercalations of limestone. The limestone deposits are frequently chalky, chalky, and porous and include a sandy component [24].

g) Injana formation (Late Miocene): This formation may be found on the eastern side of Al-Razzaza Lake, as well as on the ridges of Tar Al-Sayid and Tar Al-Najaf. Additionally, it can be found on the western side of Al-Razzaza Lake. It is made up of lenticls of grey, partly greenish silty, brownish, greenish, and yellowish sandstone, in addition to sandy calcareous claystone [24]. The lower contact with the Fat'ha formation is conformable, and it is composed of an admixture of pebbles, sands, and silts that are bound together by grey marl. The initial layer of sandstone, which is described as light grey, crumbly, and pebbly, touches the layer that is superimposed over it (Dibdibba formation).

h) Dibdibba formation (Pliocene – Pleistocene): It is mostly constituted of pebbly sandstone and sandstone, in addition to claystone, siltstone, and marl, and it also contains auxiliary gypsum in small amounts [25]. This formation, which is widely exposed along both ridges of Tar Al-Sayed and Tar Al-Najaf and occupies the top section of the exposed sequence, is the bed rock of the desert plain between Najaf and Karbala. It may be found between the two cities of Najaf and Karbala.

According to the findings of the hydrogeological previous research, the Dammam formation was considered the huge volume of water, significantly[26]. The transmissivity potential value of this formation ranges from 3.1 to 4752 m2/day, reflecting the aquifer's variability owing to fracture and porosity variance [23]. In confined aquifers, the value of the storage coefficient can be comparable to 1.2 × 10-4, but in unconfined aquifers, the value of the specific yield can be equivalent to 2.45 × 10-2 [27]. This head has the ability to create a vertical recharge that goes from Umm Er Radhuma, which is the lower aquifer, to Dammam, which is the upper aquifer [28]. In the Dammam aquifer, the piezometric head is approximately comparable to 41.97 m, which is relatively close to the head in the Umm Er Radhuma aquifer.

Many times, the flow of groundwater in the western desert may be seen moving in an eastern or northeastern direction. This is despite the fact that the western desert is located in the western hemisphere. On the other hand, the movement of groundwater can take a number of different paths across the region depending on the geographical, geological, and structural elements [29]. The direction of flow of groundwater in the Dammam aquifer, which is reflective of the general flow direction of groundwater in Iraq [30], normally travels from southwest to northeast (that is, towards the Euphrates River).

3. Materials and Methods

Seven wells in the identical region were sampled over the course of six years (2017, 2018, 2019, 2020, 2021, and 2022), and their water was examined for both major and minor components. Several thematic maps of the irrigation water quality index were made using ArcGIS 10.4.1. (IWQI).

The purpose of this research was to establish a system for evaluating the groundwater quality in the study region using the Irrigation Water Quality Index (IWQI). The suggested IWQ index is a Geographic Information System (GIS)-based technique that utilises the combination of five categories of irrigation water quality factors that have the potential to negatively affect soil quality and crop output.

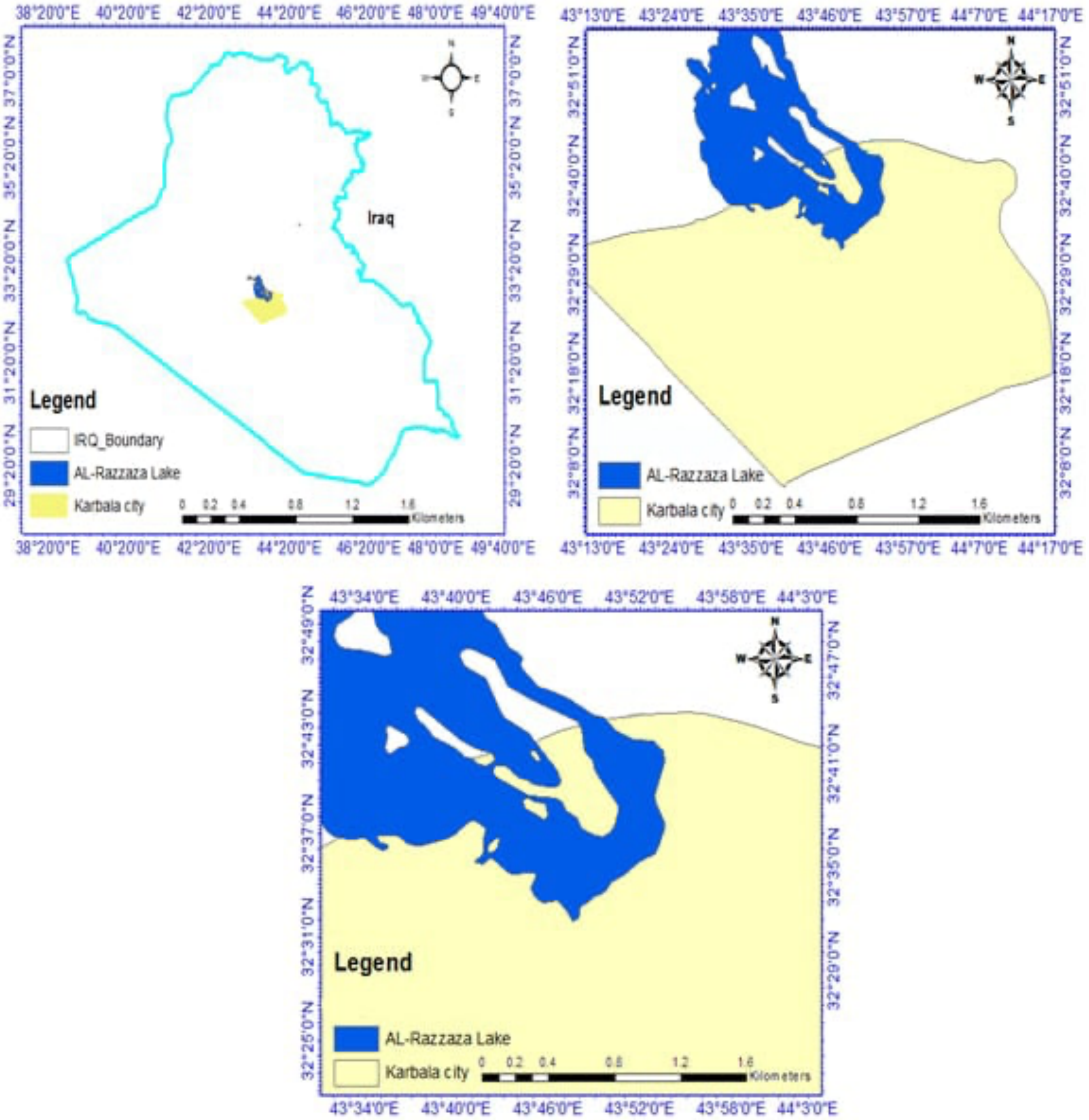

Figure 1: (a-c) Geographical location for the study area.

This method simultaneously considers the five groups. Each group's data is added up to provide an index value, which is then used to judge the quality of the irrigation water. Data from groundwater samples taken in the study area informed the application of the IWQI model. This model, which was achieved by [31], has two stages. The parameters that impact irrigation water quality most frequently were discovered in the first step. The "electrical conductivity, EC", Na+, Cl-, HCO3-, and "sodium adsorption ratio, SAR" characteristics were utilised to generate the suggested WQI. These determine the best water quality and contain the bulk of the multifactorial weight. The definition of aggregate weights (wi) and quality measurement values (qi) was defined in the second stage.

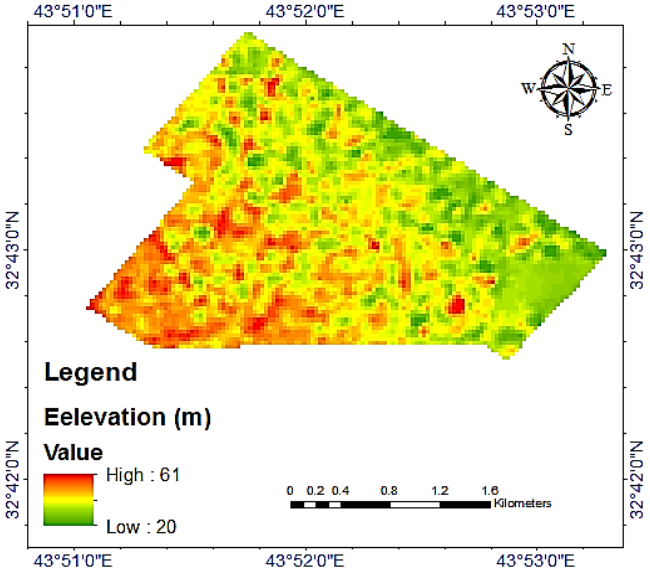

Figure 2: Digital Surface Model.

According to the criteria established by Jassim et al. [18] and the irrigation water quality parameters supplied by the University of California Committee of Consultants (UCCC), which are presented in Table 1, values of (qi) were computed based on each parameter value. A non-dimensional number was applied to indicate water quality criteria; the higher the value, the better the water quality.

The IWQI will be established to determine the groundwater quality for irrigation purposes with greater precision. This index provides a single value that, depending on the individual water quality factors, represents the overall water quality at a given time and place. This measurement cannot provide a comprehensive view of the water quality since it does not take into account a number of additional factors. This indicates that a number of major factors that offered a clear indicator for the condition of the water are dependent on the IWQI.

Most characteristics utilised to assess irrigation water quality are regional soil, cultivated crop pattern, and climatologic circumstances. In this context, GIS can create spatial patterns maps for water quality parameters, and these maps can be employed to establish comparative comparisons. The IWQI quality characteristics can be used to determine the acceptability of groundwater for drinking and irrigation.

The measured data for the research region were fed into the IWQI model posed by [16]. In order to accomplish this, it was needed to: 1) determine which factors were important for irrigation, and 2) determine how to quantify quality (qi) using aggregate weights (wi). Estimating the values of qi can be obtained using equation 1, in conjunction with the requirements described in table 1, which was dependent by [32].

Table 1: Value limitations in qi-calculation parameters.

Qi	EC(μS/cm)	SAR$(meq/L)^{1/2}$	Na^{+*}	Cl^{-*}	HCO_3^{-*}
85-100	200-750	<3	2-3	<4	1-1.5
60-85	750-1500	3-6	3-6	4-7	1.5-4.5
35-60	1500-3000	6-12	6-9	7-10	4.5-8.5
0-35	<200 or ≥3000	≥12	<2 or ≥9	≥10	<1 or ≥8.5

* meq/L

Where *qimax* is the highest value of *qi* for a certain class, *xij* is the variable's observed value, *xinf* is the value corresponding to the lower limit of the variable's class, *xamp* is the amplitude class to which the variable belongs, and *qiamp* is the amplitude of the class.

For the final class of each variable, the x_{amp} can perform an evaluation by selecting the upper limit value that was determined to be the highest based on the results of chemical and physical analysis of water samples. The values found for the weighting of each variable that was used in the calculation of IWQI were taken and given in Table 2. Also, It is possible to adopt equation 2 to determine the value of IWQI.

Table 2: The weights that were utilised in the computation of IWQI (33).

Variable	SAR	Na^+	Cl^-	HCO_3^-	EC	Total
Weight (w_i)	0.189	0.204	0.194	0.202	0.211	1.000

Water quality-specific classifications were proposed by [34] and [35] based on IWQI values; nevertheless, these classes recognised the hazards associated with using such water for soil and plants. When the IWQI readings are between “85-100”, “70-85”, “55-70”, “40-55”, and “0-40,” respectively, the water is categorised as having “No Restriction, NR,” “Low Restriction, LR,” “Moderate Restriction, MR” “High Restriction, HR” and “Severe Restriction, SR.” For illustration, the “Recommendation” for making use of water that has been categorised as SR for “Soil” will state that “its consumption irrigation should be discouraged under normal operating conditions.” May be utilised on rare occasions in exceptional circumstances.

In order to treat water that has a high SAR but a low salt concentration, gypsum must be used. Only plants that can withstand high amounts of salt should be utilised, except for waters that have extremely low concentrations of sodium, chloride, and bicarbonate ions. In order to prevent salt buildup, soils with a high concentration of salty water must have a high permeability, and an adequate supply of water must be made available.

4. Results and discussion

The final IWQI maps and values for each year are displayed in Figure (3-8) and Table (3-8), respectively. These maps are the result of geostatistical analysis, which caused the theme maps for SAR, Na+, Cl-, HCO3-, and EC to overlap with one another. Using equation 2, the spatial integration of groundwater quality mapping was done with the help of the ArcGIS Spatial Analyst extension. These figures illustrate the regional distribution of IWQ values for the research area in order to provide a description of the water’s appropriateness for irrigation. Therefore, this will be an effective tool for decision-makers to use in determining the appropriate sites of drilling wells that may be utilised for irrigation purposes. The water in the region under investigation can be categorised as having “high restriction” (HR) during the first few years, and then as having “severe restriction” (SR) for the final few years.

Table 3: Water quality in the studied area during the year of 2017.

Parameter	Well designation						
	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7
pH	7.50	7.40	7.50	7.40	7.45	7.44	7.45
EC (µS/cm)	4,700	4,910	4,530	5,630	4,150	4,080	4,600
HCO_3^- (mg/L)	490.15	168.65	191.81	231.90	416.36	200.28	226.63
Cl^- (mg/L)	1,375	1,200	1,410	1,200	921	1,060	1,082
Ca^{2+}(mg/L)	800	925	625	1,257	735	736	736
Mg^{2+}(mg/L)	550	950	625	1,293	856	850	810
Na^+(mg/L)	167.57	167.05	203.81	182.08	180.18	165.66	149.70
SAR	20.48	21.63	29.73	18.10	20.69	19.02	16.46
IWQI	42.78	49.99	46.85	45.46	44.80	51.16	50.46

Table 4: Water quality in the studied area during the year of 2018.

Parameter	Well designation						
	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7
pH	7.05	7.95	7.20	7.20	6.93	7.22	6.97
EC(µS/cm)	4,760.00	4,570.00	4,295.00	5,500.00	4,280.00	4,270.00	4,785.00
HCO_3^-(mg/L)	510.57	175.68	199.80	241.56	433.71	208.62	236.07
Cl^-(mg/L)	1,054.20	1,024.80	1,254.75	966.00	894.60	1,029.00	1,050.00
Ca^{2+}(mg/L)	650.00	590.00	380.00	820.00	432.43	432.86	432.86
Mg^{2+}(mg/L)	235.80	578.40	310.00	785.40	425.70	415.20	376.80
Na^+(mg/L)	253.89	253.11	308.80	275.89	273.00	251.00	226.82
SAR	26.25	27.73	38.12	23.21	26.53	24.38	21.10
IWQI	36.02	44.75	41.14	40.05	38.03	44.19	43.22

Table 5: Water quality in the studied area during the year of 2019.

Parameter	Well designation						
	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7
pH	6.6	8.5	6.9	7	6.4	7	6.5
EC (µS/cm)	4820	4230	4060	5370	4410	4460	4970
HCO_3^-(mg/L)	567.3	195.2	222	268.4	481.9	231.8	262.3
Cl^-(mg/L)	1004	976	1195	920	852	980	1000
Ca^{2+}(mg/L)	204.4	180.36	140.23	320.64	240.24	240.48	240.48
Mg^{2+}(mg/L)	33.67	31.72	26.84	39.04	29.28	29.28	53.68
Na^+(mg/L)	325.5	324.5	395.9	353.7	350	321.8	290.8
SAR	11.55	4.24	4.92	5.18	10.26	4.90	5.26
IWQI	24.40	33.32	28.72	28.90	25.81	32.85	33.08

Table 6. Water quality in the studied area during the year of 2020.

Parameter	Well designation						
	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7
pH	7.47	8.43	7.63	7.63	7.34	7.65	7.39
EC (µS/cm)	4,950.40	4,432.90	4,252.05	5,445.00	4,536.80	4,611.60	5,119.95
HCO_3^-(mg/L)	538.35	185.24	210.67	254.70	457.31	219.97	248.92
Cl^-(mg/L)	984.18	917.56	1,106.46	884.65	764.84	879.74	897.70
Ca^{2+}(mg/L)	193.01	169.54	133.61	279.72	168.94	150.32	159.71
Mg^{2+}(mg/L)	31.99	30.13	25.50	37.09	27.82	27.82	51.00
Na^+(mg/L)	341.11	340.06	414.89	370.66	366.79	337.23	304.75
SAR	34.97	36.93	50.77	30.91	35.34	32.47	28.10
IWQI	23.26	32.08	27.47	27.62	24.21	30.54	31.09

Table 7. Water quality in the studied area during the year of 2021.

Parameter	Well designation						
	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7
pH	6.94	7.83	7.09	7.09	6.82	7.11	6.87
EC (µS/cm)	4426.80	4010.18	3788.19	5038.28	4076.17	4023.83	4497.90
HCO_3^-(mg/L)	458.14	157.64	179.28	216.75	389.17	187.20	211.83
Cl^-(mg/L)	883.48	823.67	993.24	794.13	686.58	789.72	805.84
Ca^{2+}(mg/L)	175.50	149.19	111.90	234.27	137.97	136.46	137.28
Mg^{2+}(mg/L)	27.83	26.22	22.18	32.27	24.20	24.20	44.37
Na^+(mg/L)	368.40	367.27	448.08	400.32	396.13	364.21	329.13
SAR	37.76	39.89	54.83	33.38	38.16	35.07	30.35
IWQI	24.47	32.18	28.29	27.50	24.73	31.23	31.62

Table 8. Water quality in the studied area during the year of 2022.

Parameter	Well designation						
	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7
pH	7.32	8.04	7.55	7.55	7.27	7.57	7.32
EC (µS/cm)	3250	3420	3659.53	4447.86	4061.02	3828.72	4168.78
HCO_3^-(mg/L)	244	317.2	170.73	203.37	336.82	238.75	201.97
Cl^-(mg/L)	567.2	645.19	866.09	767.96	653.20	710.09	746.71
Ca^{2+}(mg/L)	96.2	92.18	70.51	128.99	92.75	83.99	84.90
Mg^{2+}(mg/L)	14.152	16.104	19.30	28.07	21.05	21.05	38.60
Na^+(mg/L)	445	461	483.92	432.34	427.82	393.35	355.46
SAR	40.78	43.08	59.21	36.05	41.22	37.88	32.78
IWQI	29.69	25.71	26.44	26.89	24.52	27.40	30.39

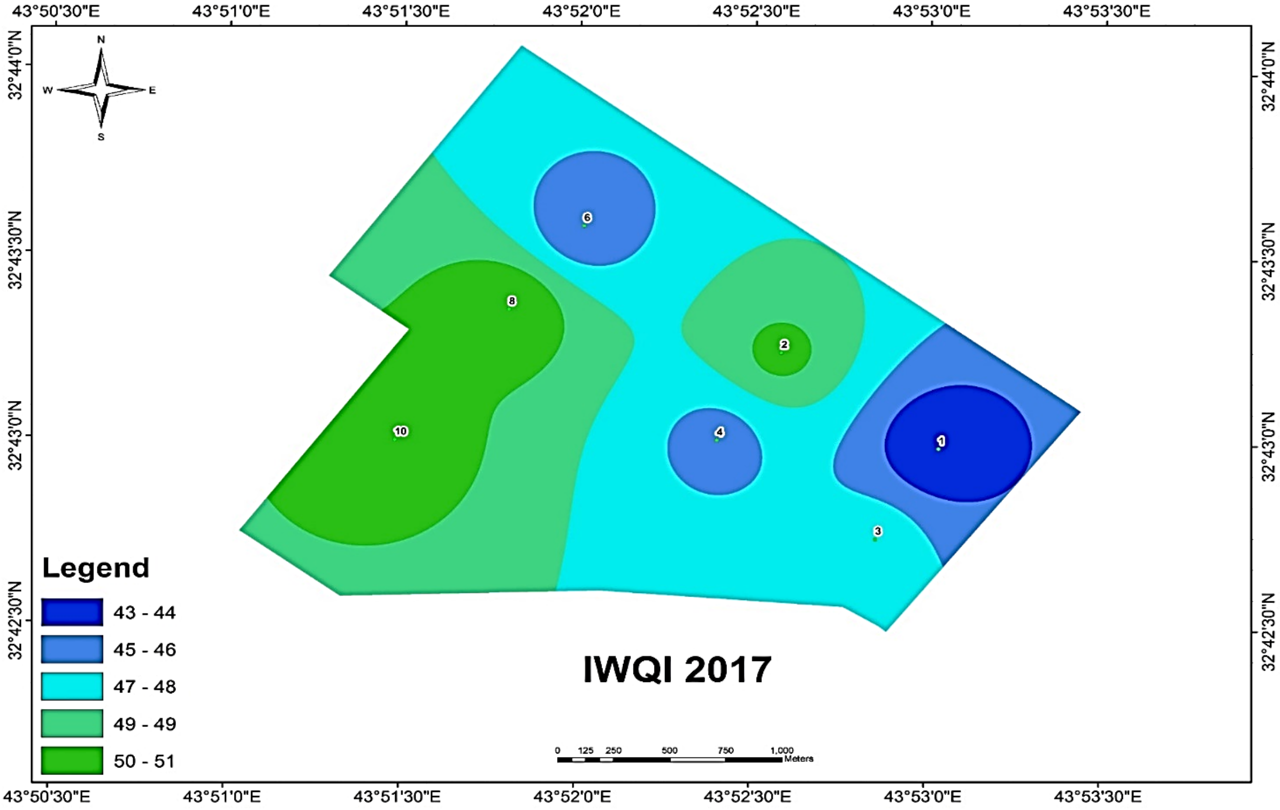

Figure 3: IWQI map for the studied area in the year 2017.

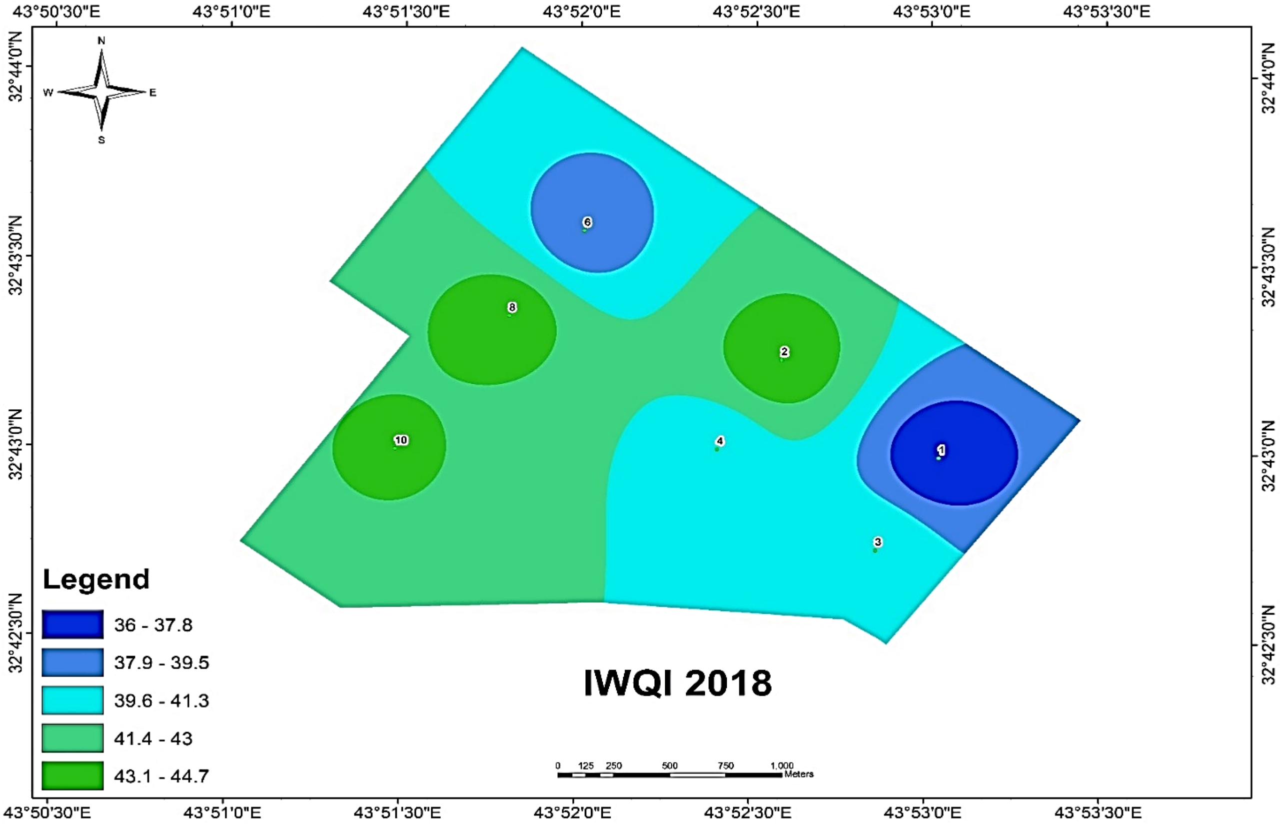

Figure 4: IWQI map for the studied area in the year 2018.

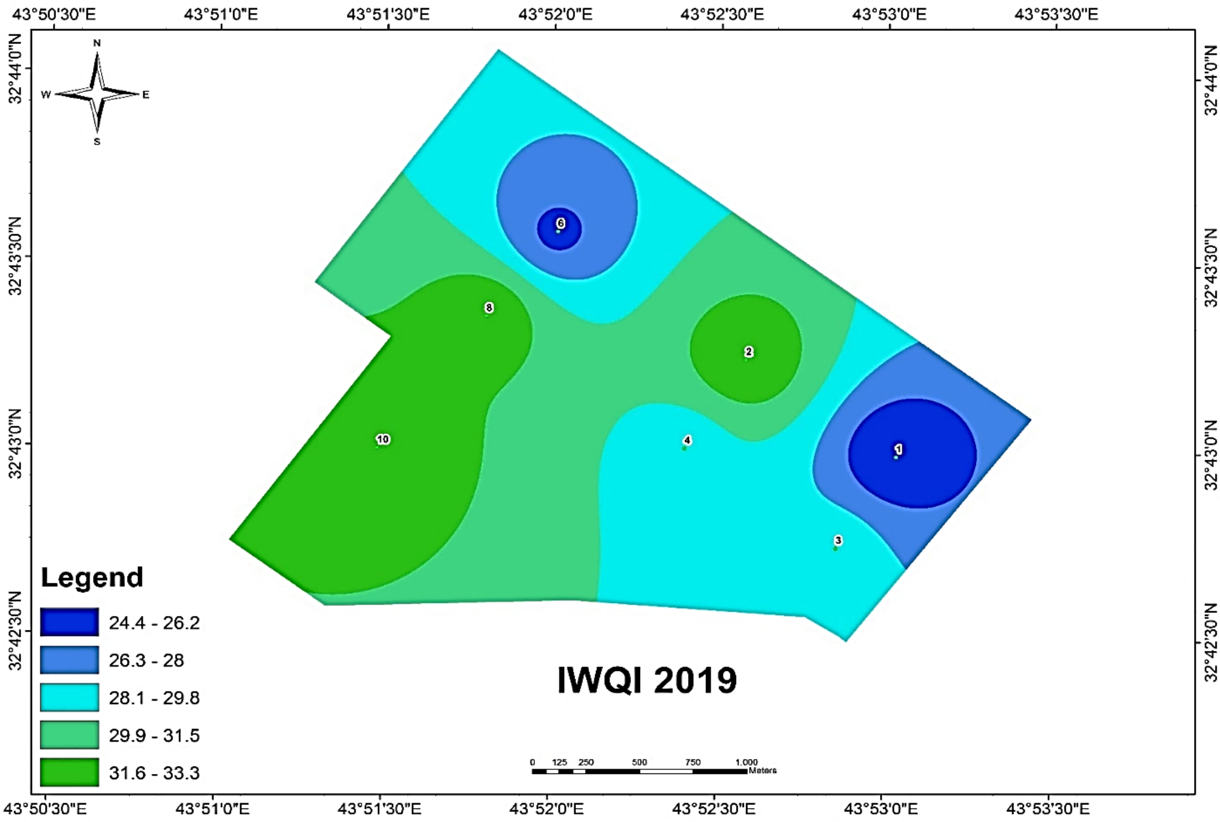

Figure 5: IWQI map for the studied area in the year 2019.

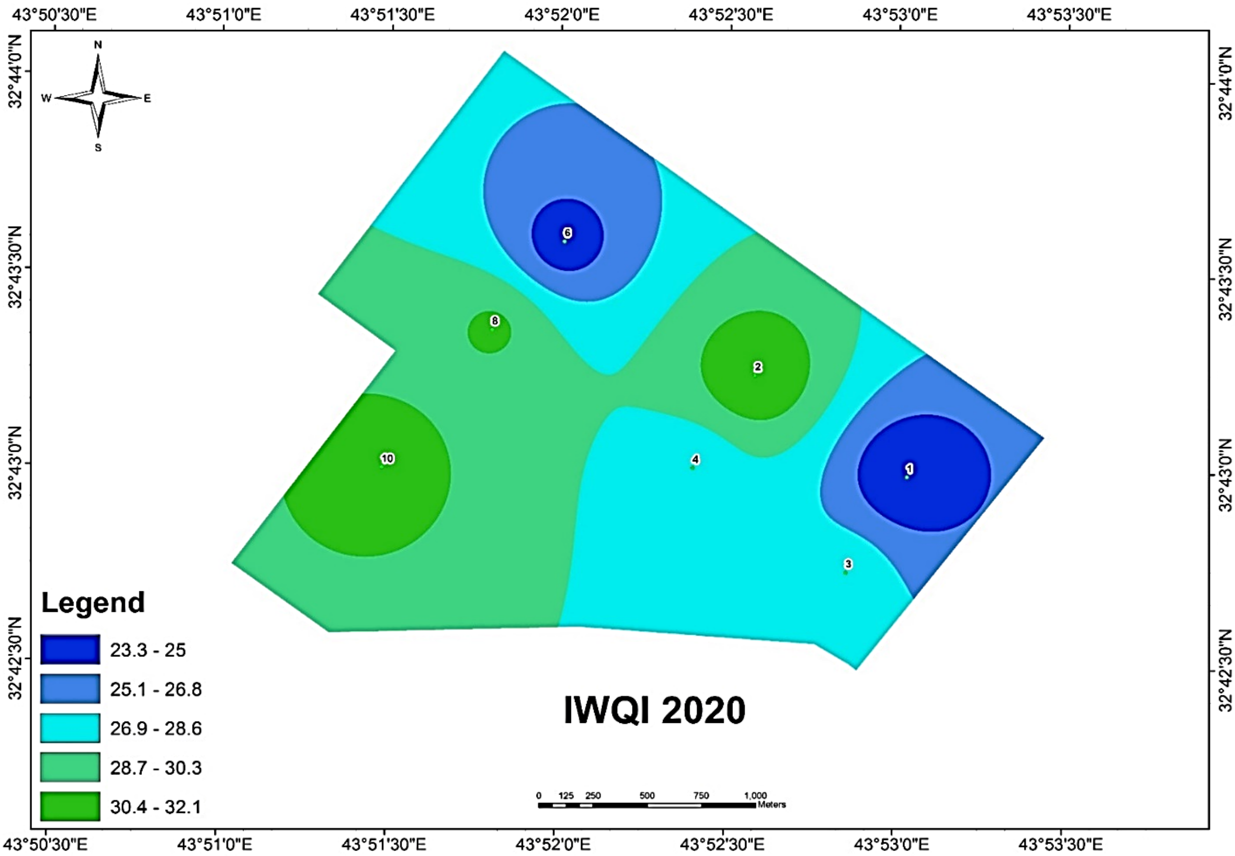

Figure 6: IWQI map for the studied area in the year 2020.

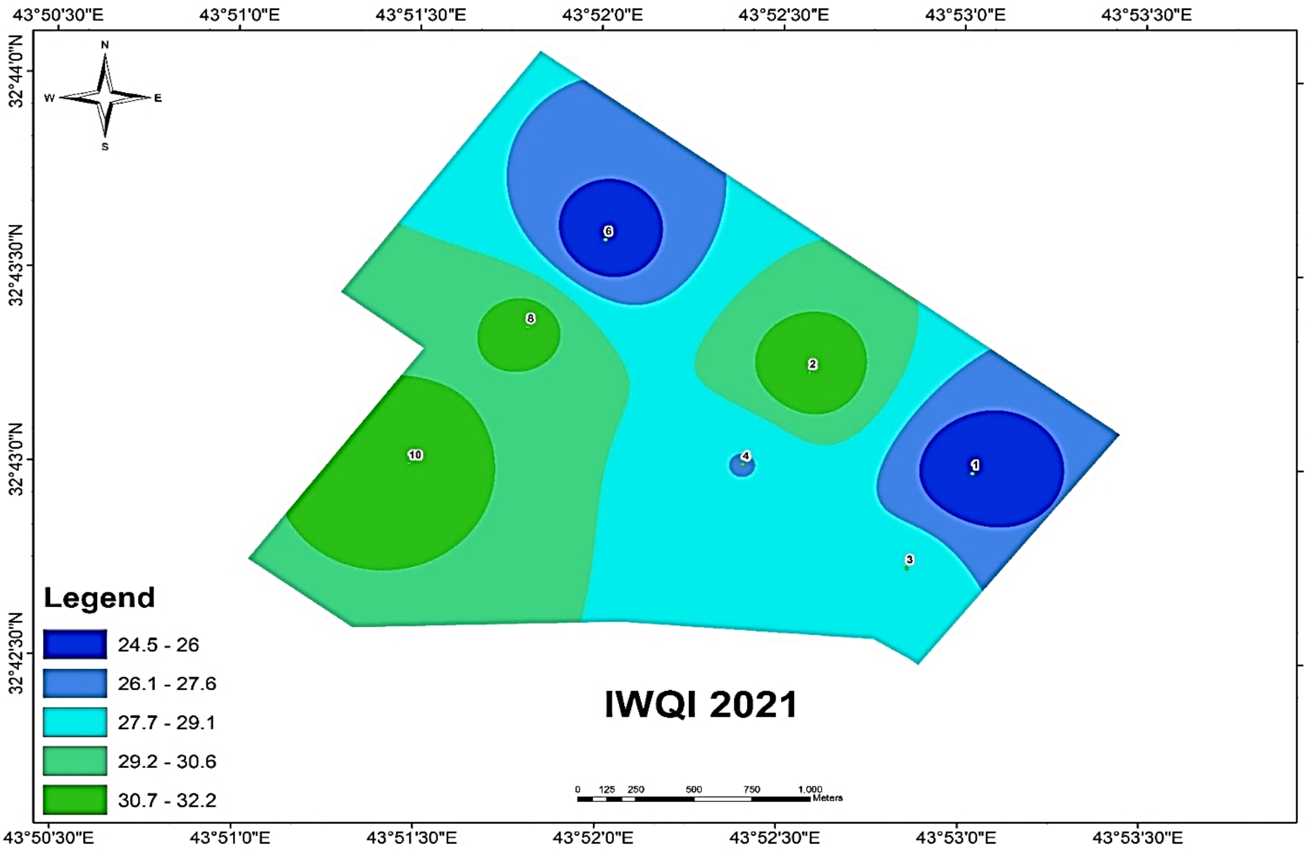

Figure 7: IWQI map for the studied area in the year 2021.

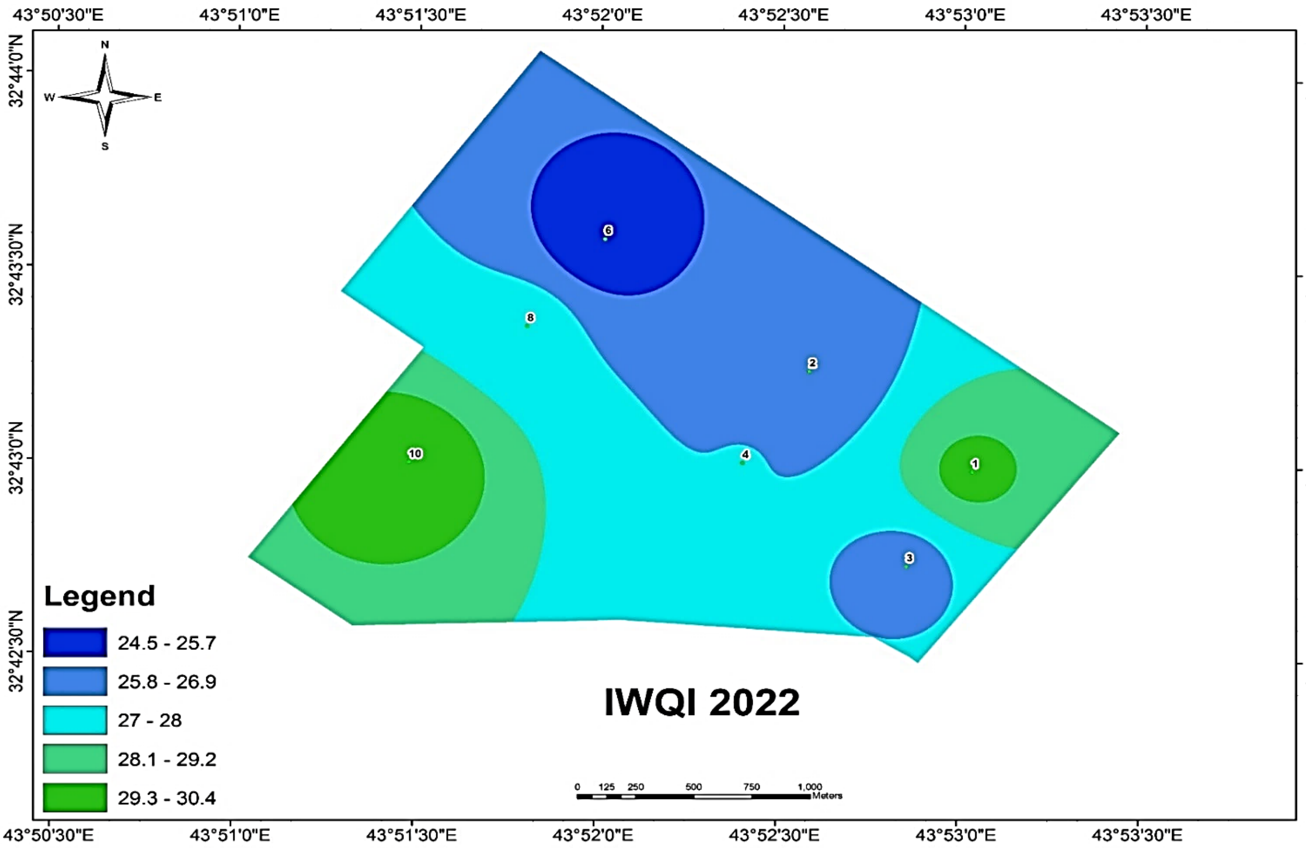

Figure 8: IWQI map for the studied area in the year 2022.

The pattern of IWQI for all wells, which declined throughout the course of the 6 study years and resulted in tightening usage limitations, is shown in Figure 4. The quality of groundwater deliberately deteriorated and became more hazardous as it moved from high to severe limits. It is crucial to remember that the study's final four years' findings showed that they were incredibly harsh, and it is thus vital to think about the potential factors that may have contributed to something like this. The city of Karbala has seen a tremendous increase in its population, which may have had an effect on the quantity of pollution and garbage in all of its forms. On the other hand, this groundwater contamination may be caused by sewage pipe network leaks and/or untreated all types of residential water that has been removed from Kerbala city.

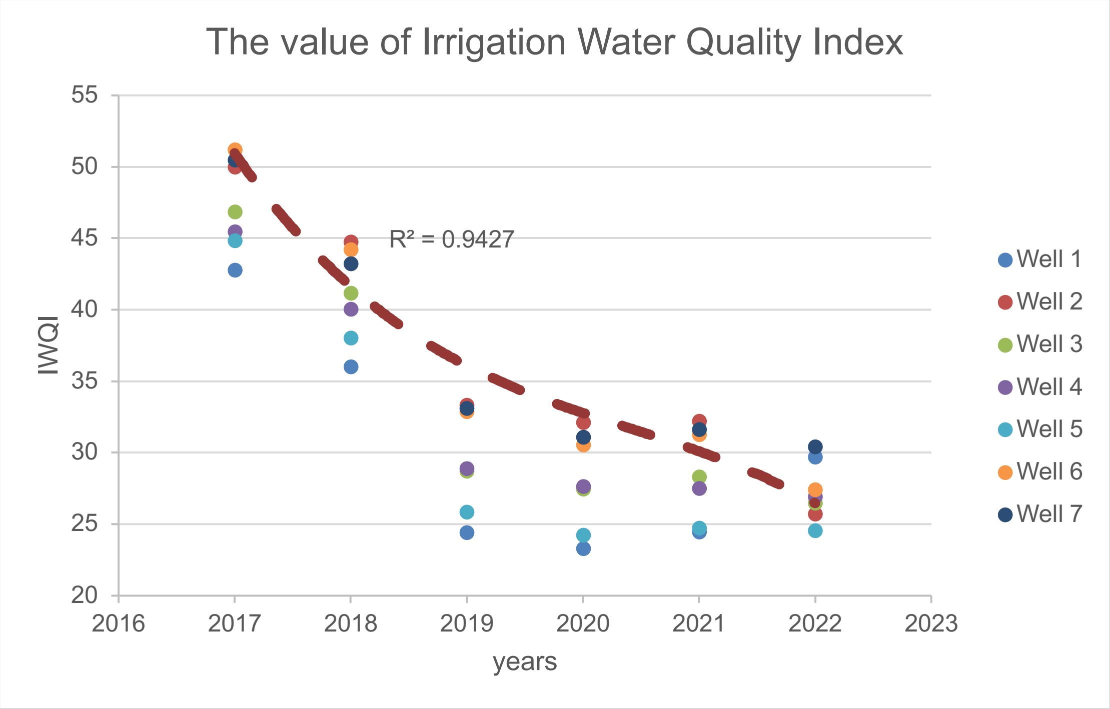

Figure 9: IWQI map for the studied area in the last 6 years.

4. Conclusions

Based on the findings of the investigation, it can be observed that there was a gradual deterioration in the quality of the groundwater in Karbala city between the years 2017 and 2022. In addition, the Integrated Water Quality Index and the Geographic Information System present an accurate picture of the state of the groundwater. The findings indicate that the irrigation water quality indexes (IWQIs) for the wells in the research region may be classified as "High Restriction," or HR, in the early years, and as "Severe Restriction," or SR, in the latter years throughout the course of a period of six years (2017-2022). This is referring to the potential dangers that might arise in the years to come if the necessary steps are not taken to stop the deterioration in the quality of the groundwater. In addition to coming up with workable answers to the problems with the water sources.

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