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Evaluation of the Water Quality Index of Baghdad's Groundwater Using GIS

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ABSTRACT

Groundwater is an essential source due to its reliable quality and availability that characterizes it as a water resource. Therefore, studying groundwater and its characteristics requires more attention. This study aims to evaluate the suitability of groundwater quality for drinking purposes in Baghdad city, Iraq through water quality index (WQI) under geographic information systems (GIS) environment. The study area is in central Iraq, with an approximate area of 900 $km2$. Groundwater wells hydrochemistry data were collected from Ministry of Water Resources in Iraq representing the sites of 48 wells within the study area for two periods; 2013 and 2022. The IDW interpolation method then used in GIS to generate spatial distribution of the water quality index values across the study area. WQI values in the study area ranges from 23.3-262.2 (2013) and from 45.5-470.5 (2022). According to the results, only 4 and 1 wells (17% and 4%) were suitable for drinking purposes in 2013 and 2022 respectively, while 20 and 23 wells (83% and 96%) were classified as unsuitable for drinking purposes. The study concluded that the variations in the WQI values for wells in the city of Baghdad that are caused by water leaking from sewerage networks and the incomplete treatment of sewage that is discharged into the Tigris River. Study recommends establishing water treatment facilities to purify the unsuitable waters for drinking Therefore it can be a reliable source of drinking water in the study area.

Keywords: Groundwater Suitability Analysis, Baghdad, GIS, IDW, Water quality for drinking.

Introduction

Water is one of the most essential elements for human life, without ensuring the existence of water. The country cannot maintain its economic, social, and political stability. Developed countries are aware of the vital importance of water resources. Water resource management planning aims to allocate water equitably to meet needs. Water is an essential resource for all living things on Earth. Only 3% of the world's water is fresh water, and about two-thirds of it is in the form of ice and glaciers. Over time, the water runs low and access to clean, potable water is limited [1].

Over the world, in the last decades, the issue of water resources scarcity has increased dramatically. arid and semi-arid regions are impacted more aggressively by this problem, thus makes North Africa and Middle East countries among the most regions who suffer from water scarcity[2]. Trans-boundary water resources such as rivers and groundwater aquifers are one of the struggles that these regions face beside the scarcity of these resources[3]. By having about 60% of the renewable water resources (such as rivers) as shared resources with the neighboring countries, Iraq is recognized as one of the most transboundary water resources dependent countries [4].

Tigris river's water has been used for several purposes (such as drinking and irrigation) in the city of Baghdad. Despite the fact that this river has faced many problems including low recharge rates as a result of dams' construction in the surrounding countries and the contamination by industrial and agricultural wastewater discharge. These most pressing issues raised the need for either finding a new water resources or assessing the current groundwater resources which considered as a reliable source as the groundwater wells are already exist in Baghdad city and can support the current demand on water resources.

Assessment of groundwater quality is a crucial step to determine its suitability for many purposes including irrigation and domestic. This can be achieved by analyzing and studying the cations and anions present in the water. Groundwater pollution from anthropogenic sources (such as landfill leachate infiltration, pesticides and fertilizers, and saltwater intrusion) or it could be from the composition of aquifer material and its interaction with groundwater. Several studies have been conducted to assess groundwater chemistry and suitability for many purposes in many countries –[9].

The purpose of this study is to evaluate the suitability of groundwater wells in Baghdad for drinking purposes using the water quality index (WQI) method under the geographic information systems (GIS) environment.

1. Materials and Methods

1.1 Study Area

The study area is located between 32º 50′ - 33º 40′ N and 43º 50′- 44º30′ E. it covers an area that is approximately 2864 km^2 (Figure 1). Baghdad has a warm and dry summer climate and a cool and humid winter climate, with yearly precipitation rates that range anywhere from 0.05 to 24.66 millimeters. The average temperature for the month is between 9.64 and 35.39 degrees Celsius, and annual evaporation rate ranges from 66.85 to 530 millimeters. Compared to temperature and evaporation, relative humidity is low. Geologically, the study area is characterized by relatively simple Pleistocene deposits and is dominated by Holocene deposits [10]. Changes in the environment and water systems have been precipitated by several factors, including population growth, increased municipal, industrial, and agricultural activities, and other practices, and natural climatic shifts that have contributed to global warming. This has had a significant impact on water resources quality, including the quality of groundwater [11]. 72.69%, 25%, and 2.31 % of the total area is made up of urban, agricultural, and industrial regions, respectively. These percentages demonstrated the possibility of elevated pollution as a result of population growth[12].

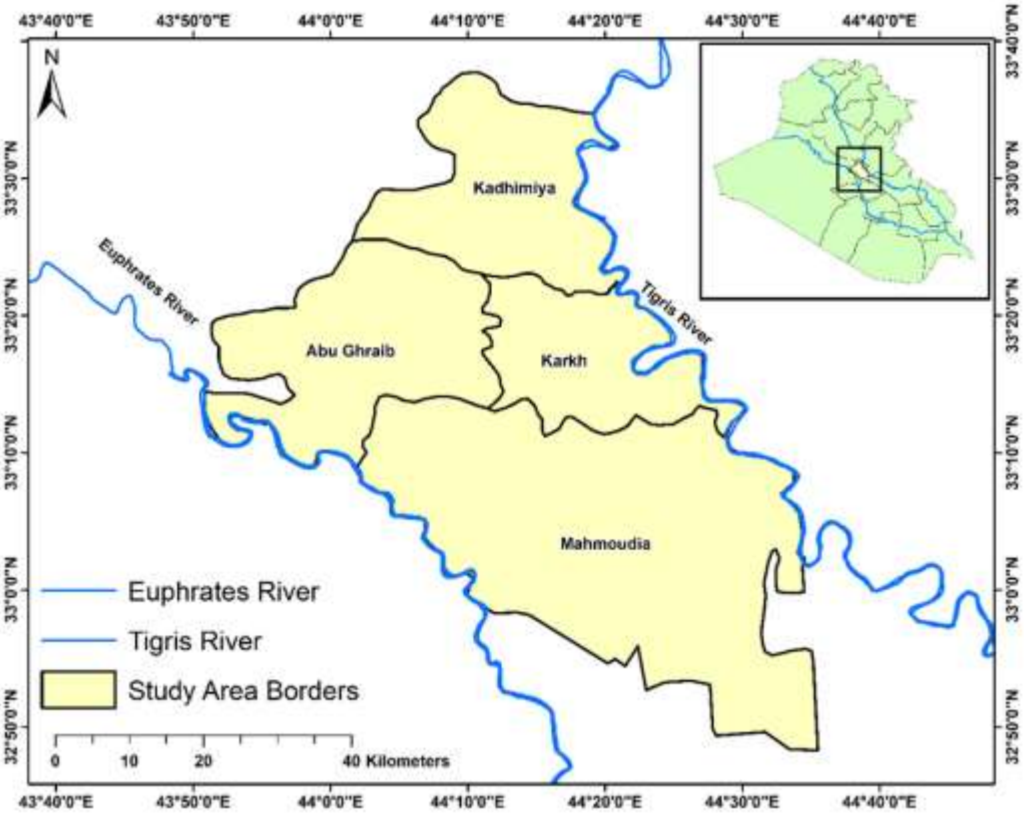

Figure 1. Study area map

2.2 Sampling and Analysis

A total of 48 wells were selected for two study periods (2013 and 2022) distributed within the borders of Baghdad. Well hydrochemistry data was obtained from the Ministry of Water Resources of Iraq, these parameters includes: pH, TDS, Ca2+, Mg2+, Na+ , K+ , Cl-, HCO3-, SO4-2, and NO3-. The chemical composition for these groundwater wells is shown in Table 1.

Table 1: Summary of study wells and their parameters

Well ID	pH	TDS	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	HCO$_3^-$	SO$_4^{-2}$	NO$_3^-$	EC	Easting (DD)	Northing (DD)
		2013											
1	7.27	1103	4.5	98	71	143	191	483	94	8	1475	44.246972	33.099972
2	7.12	889	4	81	65	100	167	361	49	1.3	1173	44.289917	33.110806
3	7.32	551	1.11	53	25	41	99	89	117	4.5	796	44.208889	33.061917
4	7.99	1265	4	112	75	165	167	584	65	2.5	1775	44.412767	33.067253
5	7.33	2547	1	373	98	136	465	681	358	2	3590	44.036694	33.213417
6	7.31	5222	9.5	720	197	419	989	1549	541	4	7660	44.070139	33.278889

7	7.21	1812	3.5	235	52	163	303	520	208	2.5	2640	44.178333	33.390278
8	7.11	1857	13.1	239	111	172	542	487	164	2	2710	44.213636	33.28049
9	7.14	2700	6.6	311	134	225	420	920	288	0.11	4020	44.394917	33.373083
10	7.11	780	2.9	92	37	66.1	128	216.1	119	6	1092	44.364	33.325111
11	7.19	628	3.5	235	40	52	303	520	208	2.5	895	44.270833	33.307222
12	7.21	2400	15	369	106	241	486	925	240	4	3140	44.22	33.376111
13	7.55	5500	14	759	233	419	1029	1728	530	7	7160	44.190556	33.476389
14	7.35	950	5	88	68	108	182	379	51	7.5	1268	44.380406	32.961807
15	7.54	5083	10.9	721	198	419	990	1557	539	3.4	7420	44.143611	33.299444
16	7.64	3591	30	530	158	379	748	1399	336	2.1	4790	44.380556	33.261667
17	7.04	1850	3.8	214	112	195	471	420	393	6	2250	44.463578	32.955297
18	7.32	508	1.8	75	35	60	185	168	23	1.2	826	44.223833	33.517585
19	7.15	2211	5	321	81	180	330	680	447	7.8	3240	44.124988	33.167741
20	7.17	2268	3	376	91	139	467	679	352	4	2920	44.24575	33.24967
21	7.58	2900	80	413	125	262	581	1000	448	6.9	3710	44.497826	33.13703
22	7.49	296	1.1	16	12	25	50	10	59	1	360	44.209444	33.196389
23	7.94	2761	2.5	376	105	223	531	770	308	4.9	3440	44.259761	33.506065
24	7.9	950	5	88	68	108	182	379	51	7.5	1268	44.312722	33.166833
		2022											
25	7.22	6920	715	535	41.925	70	1542	829	2163	1.3	10690	44.250194	33.238611
26	7.3	977	70	66	85	3.6	176	110	440	0.2	1499	44.298417	33.132861
27	7.3	1481	134	69	244	6	208	188	550	1.2	2190	44.232342	33.118389
28	7.25	1252	128	88	135	12	251	61	557	0.3	1935	44.275869	33.122889
29	7.18	7265	630	356	1024	115	1448	1096	2470	1.2	11190	44.228028	33.276889
30	7.11	5480	479	294	879	68	1169	663	1840	1.1	8430	44.033694	33.310361
31	7.1	22	26	154	223	10	55	210	801	0.1	347	44.14438	33.271611

	9	44	7				3			5	0	9	
32	7.25	5940	528	361	920	68	1264	759	1940	1.1	9130	44.366583	33.152722
33	7.12	2570	256	99	408	16	575	440	744	0.2	3970	44.36325	33.136139
34	7.18	1925	177	118	262	12	582	204	534	0.1	2980	44.259528	33.310889
35	7.19	8360	814	532	1254	140	2067	613	2865	1.2	12950	44.214639	33.249528
36	7.22	820	70	53	120	2	245	72	288	1.4	1258	44.365639	33.322417
37	7.22	2830	294	126	444	18	630	485	803	1.1	4380	44.367869	33.235794
38	7.17	1430	135	70	245	9	209	189	557	1.3	2210	44.275389	33.469944
39	7.19	1935	178	119	263	12	590	200	550	0.8	2990	44.274944	33.470167
40	7.18	1082	60	33	160	1.6	212	74	254	1.2	1558	44.403611	33.304722
41	7.2	800	60	40	110	2	213	31	200	0.5	1123	44.183306	33.464806
42	7.2	1600	132	89	137	11	245	65	585	2.7	2460	44.307222	33.419056
43	7.25	2680	266	105	414	16	590	457	769	0.2	4020	44.388444	33.041967
44	7.18	1520	166	51	229	5	283	142	562	2	2330	44.166667	33.250556
45	7.35	661	61	38	75	2	183	23	181	0.7	950	44.202778	33.300833
46	7.31	3500	312	146	572	11	677	482	1204	2	5390	44.158333	33.275833
47	7.13	4480	420	200	724	12	994	542	1562	2	6920	44.405556	33.233333
48	7.25	3340	280	135	525	88	644	470	1176	2	5170	44.038889	33.239444

The spatial distribution for these wells is shown in Figure 2.

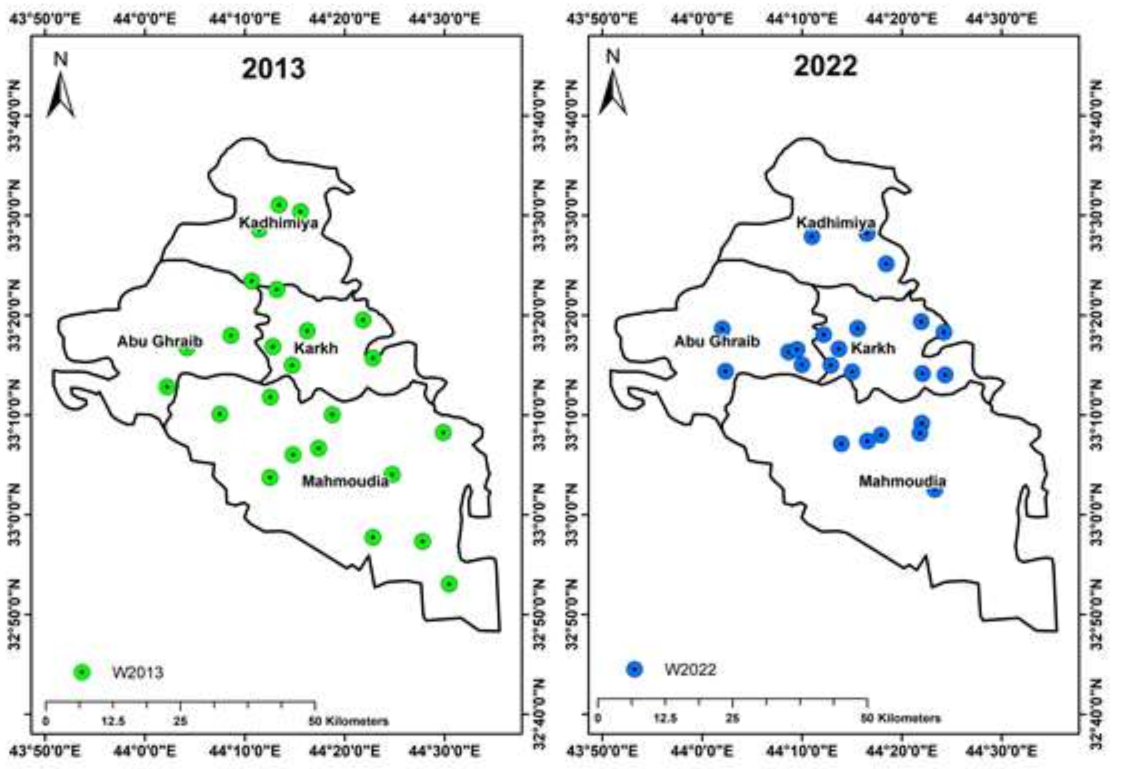

Figure 2: Location map for groundwater wells for both study periods (2013 and 2022)

2.3 Water quality index (WQI) calculation

The weighted arithmetic index was used to determine the water quality index (WQI) for the purpose of evaluating the safety of the water supply for human consumption[13]. In order to calculate the WQI, Iraqi standard specification for drinking water [14]. The water quality index was calculated by factoring in the concentrations of TDS, Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, Cl^{-}, HCO_3^{-} , NO_3^{-}, and SO_4^{-2}. In three steps, an index of water quality (WQI) was determined as follows:

1.Each of the physicochemical parameters was given a weight (wi) according to its importance in establishing the quality of the drinking water. Depending on its importance, each water characteristic was given a weight between 1 and 5 (see Table 3).

2.Wi, the relative weight, is determined using the following formula:

$$\mathrm{Wi}=\frac{\mathrm{Wi}}{\sum_{i=1}^{n}\mathrm{wi}}\text{...........5}$$

where n is the number of parameters, Wi is the relative weight, and Wi is the weight of each parameter.

3.To calculate a quality score (qi), each parameter's each water sample's concentration is divided by the Iraq's 2009 guideline, and the result is multiplied by 100:

$$qi=\frac{ci}{si}\times 100\text{........6}$$

qi: quality score; Each water sample's concentration of physicochemical parameters (ci) and the Iraq's 2009 guideline drinking water standard concentration (si) are given in milligrammes per milliliter (Table 2).

4.Using the following formulae, we can determine the overall water quality index (WQI) as the sum of the Sl-indices for each chemical parameter.

$$\mathrm{Sli}=\mathrm{wi}\times\mathrm{qi}\text{.........7}$$

$$\mathrm{WQI}=\sum\mathrm{Sli}$$

The index of water quality (WQI) predicted values can be divided into five categories as shown in (Table 3) [15],[13][16]

Table 2: Iraq's 2009 guideline, weights[14], and relative weights for study parameters[16],[17].

parameter	Iraq's 2009 guideli	Wi	Relative weight

	ne drinking water limit		**(Wi)**
Na (mg/1)	200	4	0.10811
TDS (mg/1)	1000	4	0.10811
Mg^{+2} (mg/1)	100	2	0.05405
HCO_3^- (mg/1)	350	3	0.08108
SO_4^{-2} (mg/1)	400	4	0.10811
Cl^- (mg/1)	350	5	0.13514
NO_3^- (mg/1)	50	5	0.13514
Ca^{+2} (mg/1)	150	2	0.05405
K^+ (mg/1)	12	1	0.02703
EC µS/cm	1500	3	0.08108
PH	6.5	4	0.10811
		$\sum wi = 37$	$\sum Wi = 1$

Table 3: The status of the water quality and the water quality index [18]

WQI	water type
< 25	Excellent water
26 - 50	Good water
51 - 75	Poor water
76 - 100	Very Poor water
>100	Unsuitable for drinking

2.4 Spatial distribution for study parameters

Interpolation technique was used to obtain the spatial distribution for study parameters. There are many methods for interpolation including inverse distance weighting (IDW), kriging, and nearest neighbor interpolation. IDW technique was used in the present study which is based on weighting of distances to estimate the pixel values using a combination of linear-weighted samples set [19]. ESRI's ArcGIS 10.6.1 software was used to run IDW process in order to interpolate the study chemical parameters.

2. Result discussions

2.1 WQI results

According to the weighted arithmetic index method, the coefficients of NO_3^-, Cl^-, SO_4^{-2}, and TDS were given the greatest amount of weight because the role that they play in determining the quality of the water is more significant than that of the other chemical properties coefficients. The remaining chemical property coefficients were given less weight because they do not have a negative impact on the quality of the groundwater. WQI values were calculated for all studied wells within the study area, the summary of these values is demonstrated by Table 3 and Figure3.

Table 3: Summary of WQI classification for study wells for 2013 and 2022.

		In 2013		In 2022	
WQI	Water quality	Number of wells	% of wells	Number of wells	% of wells
< 25	Excellent	22	4%	-	-
26 - 50	Good water	3,10,18	13%	45	4%
51 - 75	Poor water	1,2,4,11,14,24	25%	26,36,40,41	17%
76 - 100	Very Poor water	7	4%	27,28,38,42,44	21%

>100	Unsuitable for drinking	5,6,8,9,12,13,15,16,17,19,20,21,23	54%	25,29,30,31,32,33,34,35,37,39,43,46,47,48	58%

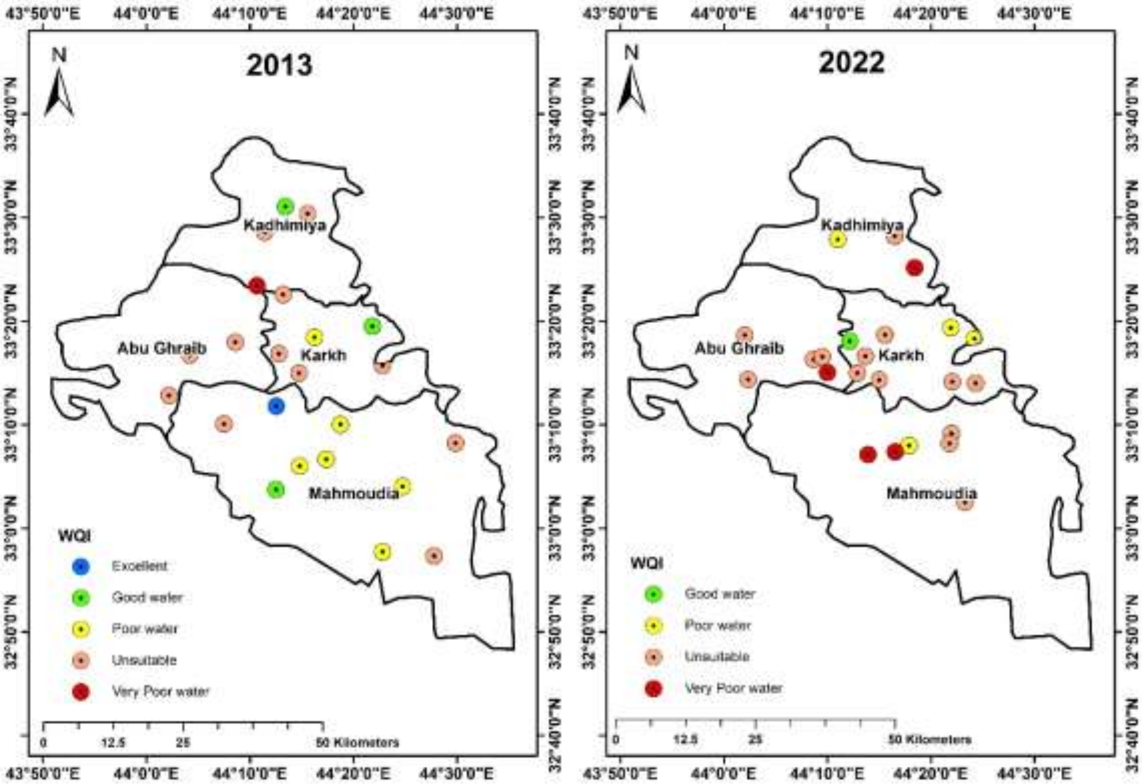

Figure 3: Wells suitability for drinking in both study period.

The WQI values for each studied well is shown in Table 4 below.

Table 4: WQI values for study area wells and their classification of suitability for drinking purposes.

Well ID	WQI	Suitability for Drinking
2013		
1	65.0	Poor water
2	52.6	Poor water
3	37.1	Good water
4	69.8	Poor water
5	129.0	Unsuitable
6	251.1	Unsuitable
7	92.1	Very Poor water
8	103.7	Unsuitable
9	133.2	Unsuitable
10	48.2	Good water
11	68.8	Poor water
12	129.7	Unsuitable
13	262.2	Unsuitable
14	57.5	Poor water
15	248.8	Unsuitable
16	187.9	Unsuitable
17	102.4	Unsuitable
18	40.3	Good water
19	118.5	Unsuitable
20	122.4	Unsuitable
21	156.4	Unsuitable
22	23.3	Excellent
23	136.5	Unsuitable
24	58.4	Poor water

2022		
25	339.4	Unsuitable
26	62.8	Poor water
27	89.3	Very Poor water
28	79.0	Very Poor water
29	397.0	Unsuitable
30	308.1	Unsuitable
31	132.9	Unsuitable
32	333.3	Unsuitable
33	150.3	Unsuitable
34	117.5	Unsuitable
35	470.5	Unsuitable
36	58.8	Poor water
37	165.3	Unsuitable
38	89.1	Very Poor water
39	118.6	Unsuitable
40	61.7	Poor water
41	51.5	Poor water
42	87.1	Very Poor water
43	154.7	Unsuitable
44	92.1	Very Poor water
45	45.5	Good water
46	199.6	Unsuitable
47	256.5	Unsuitable
48	190.2	Unsuitable

2.2 Groundwater suitability for drinking

IDW technique was used to interpolate WQI values as well, the spatial distribution for these values in the study area is shown in Figure 4.

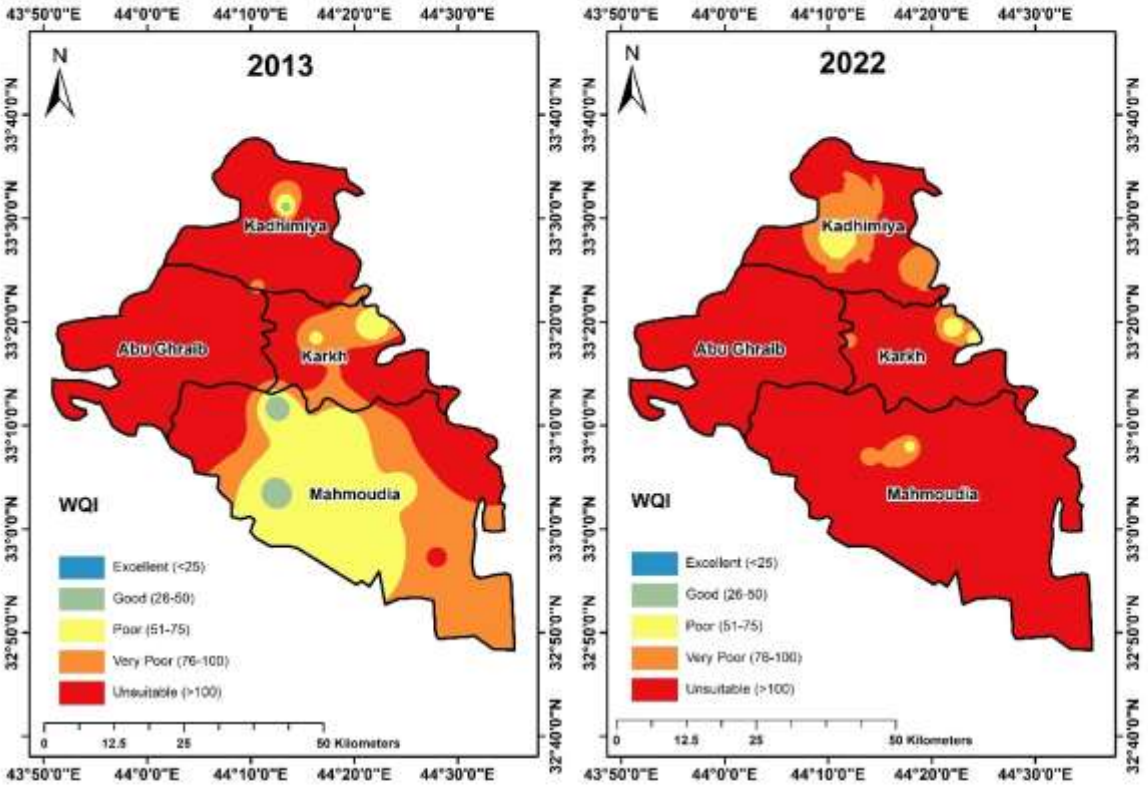

Figure 4: IWQI values mapping for study area during the year of 2013 and 2022.

As shown in figure 4, the values of information quality standards decreased significantly in 2022 compared with 2013, particularly in the northern regions (Kadhimiyah), and south of Baghdad (Mahmudiyah area) which indicate a significant deterioration in the quality of groundwater for drinking purposes, can be attributed to this year's scarcity of rainwater, as well as to the characteristics of Baghdad's aquifer, which is considered a sedimentary plain with high infiltration rates [20]. Also, in the Mahmudiyah area, the deterioration of groundwater quality was the most due to high depletion occurring in the area where agricultural areas and water quality changed from appropriate and weak to poor fit and from 2013 to 2022. The Abu Ghraib area was less improved than other Baghdad neighbourhoods where the quality of groundwater remains within very poor to inappropriate limits because it contains many agricultural projects.

By examining the results of water quality status and classifications, the results revealed that only one well in 2013 has an excellent suitability for drinking purposes, 3 and 1 wells (13% and 4%) have good fit, 6 and 4 wells (25% and 17%) have poor fit, 1 and 5 wells (4% and 21%) They have a very poor fit and 13 and 15 wells (54% and 58%) that were inappropriate for drinking purposes in 2013 and 2022 respectively.

Compared to Iraq's 2009 indicative drinking water, groundwater quality in the majority of the wells studied (54% in 2013 and 58% in 2022) was found to be unsuitable for drinking, however, they can be used for other purposes such as industrial, agricultural and other uses.

3. Conclusions

The province of Baghdad is characterized by a high population density in addition to industrial and human activities and water leakage from sewage networks, which contribute to the formation of a shallow aquifer of variable nature. The mapping of groundwater quality has been conducted using WQI and GIS techniques, both of which have the potential to provide extremely helpful and effective tools for spatial mapping and assessment of water resources to help decisionmakers in gaining a better understanding of the current conditions of groundwater quality and the future usage improvement potential for. Using the GIS mapping capabilities, it's possible to study the hydro-chemical properties of groundwater, to adopt this as a strategy for digging new groundwater wells and to use this for continuous monitoring of the current wells, which allows them to save time, effort, and cost while still achieving high-accuracy results. The Water Quality Index is a beneficial assessment of the overall water quality situation across two periods and is important in determining the right treatment strategy to meet the requirements. It does this by comparing the water's quality over both times. Users and those in charge of making decisions receive information from the WQI regarding the parameters of the water quality. The indicators are, for the most part, expressed simply, which paves the way for the interpretation of data that might be used to monitor groundwater quality parameters.

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