Journal of Engineering
journal homepage: www.joe.uobaghdad.edu.iq
Number 3 Volume 27 March 2021

Civil and Architectural Engineering

Using Geographic Information Systems (GIS) Program and Water Quality Index (WQI) to Assess and Manage Groundwater Quality in the City of Baghdad

Jassim Mohammed Abd Al-Waeli*
B.Sc. Civil Engineering
Engineering College, University of Baghdad,
Baghdad, Iraq
E-mail:jassim_alwoaeli@yahoo.com

Sura Kareem Ali Alobaidi
Asst. Prof. Ph.D.
College of Engineering-University of Baghdad
Baghdad, Iraq
E-mail:srak39@yahoo.com

Athraa Hashim Mohammed
Asst. Prof. Ph.D.
College of Engineering-University of Baghdad
Baghdad, Iraq
E-mail:athraram2004@yahoo.com

ABSTRACT

Groundwater is an essential source because of its high quality and continuous availability characterize this water resource. Therefore, the study of groundwater has required more attention. The present study aims to assess and manage groundwater quality's suitability for various purposes through the Geographical Information System GIS and the Water Quality Index WQI. The study area is located in the city of Baghdad in central Iraq, with an approximate area of 900km^2, data were collected from the relevant official departments representing the locations of 97 wells of groundwater in the study area for the year 2019, as it included physicochemical parameters such as pH, EC, TDS, Na, K, Mg, Ca, Cl, HCO_3 , SO_4 and NO_3 . It used (kriging method) in the geographic information system to generate the groundwater physical and chemical parameters' spatial distribution and the water quality index map. To estimate the water quality index, ten parameters were considered pH, TDS, Na, K, Mg, Ca, Cl, HCO_3 , SO_4 , and NO_3 . The estimated WQI value for groundwater samples in the study area ranges from 50 to 300. Based on the analysis, most of the area under study falls approximately 70% in poor water class and 30% in good water class, where the distribution of the groundwater samples with respect to their quality classes such as excellent, good, poor, very poor and unfit for human drinking purpose, was found to be 3 %, 30 %, 33 %, 12 %, and 20 %, respectively.

Keywords: GIS, Groundwater Wells, spatial distribution, Baghdad City, groundwater quality.

---

*Corresponding author
Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2021.03.07

Article received: 7/10 /2020
Article accepted: 23/11/2020
Article published:1/3/2021

استخدام برنامج نظم المعلومات الجغرافية (GIS) ومؤشر جودة المياه (WQI) لتقييم وإدارة جودة المياه الجوفية في مدينة بغداد

جاسم محمد عبد الوائلي *
بكالوريوس هندسة مدني
كلية الهندسة / جامعة بغداد

د. سرى كريم علي العبيدي
أستاذ مساعد
كلية الهندسة /جامعة بغداد

د. عذراء هاشم محمد
أستاذ مساعد
كلية الهندسة /جامعة بغداد

الخلاصة

تعتبر المياه الجوفية مصدرًا مهمًا لأن هذا المورد المائي يتميز بجودته العالية وتوفره المستمر لذلك تتطلب دراسة المياه الجوفية مزيدًا من الاهتمام، تهدف الدراسة الحالية إلى تقييم وإدارة جودة المياه الجوفية الملائمة لأغراض مختلفة من خلال نظام المعلومات الجغرافية (GIS) ومؤشر جودة المياه (WQI). تقع منطقة الدراسة في مدينة بغداد وسط العراق بمساحة تقريبية 900 كيلو متر مربع، وتم جمع البيانات من الدوائر الرسمية ذات العلاقة التي تمثل مواقع 97 بئراً للمياه الجوفية في منطقة الدراسة لعام 2019 حيث اشتملت على متغيرات فيزيائية كيميائية مثل (pH , EC , TDS , Na , K , Mg , Ca , Cl , HCO_3 , SO_4, NO_3) تم استخدام طريقة (kriging) في برنامج نظم المعلومات الجغرافية لأنشاء التوزيع المكاني للمعايير الفيزيائية والكيميائية للمياه الجوفية وخريطة مؤشر جودة المياه . ولتقدير مؤشر جودة المياه الجوفية تم النظر في عشر محددات (PH, TDS, Na, K, Mg, Ca, Cl, HCO_3 SO_4 , NO_3) وكانت القيمة التقديرية لـ (WQI) لعينات المياه الجوفية في منطقة الدراسة تتراوح من 50 إلى 300 . وبناءً على التحليل تقع معظم المنطقة قيد الدراسة 70٪ منها تقريبا في فئة المياه الرديئة و30٪ في فئة المياه الجيدة حيث تم توزيع عينات المياه الجوفية فيما يتعلق بفئات مؤشر الجودة ممتاز، جيد، ضعيف، ضعيف جدًا وغير صالح لشرب الإنسان وكانت النتائج 3٪، 30٪، 33٪، 12٪، 20٪ على التوالي.

الكلمات الرئيسية: نظم المعلومات الجغرافية، مؤشر نوعية المياه، أبار المياه الجوفية، التوزيع المكاني، مدينة بغداد

1. INTRODUCTION

Groundwater is generally reliable and high-quality resources if the appropriate conditions are available, so care must be taken to prevent contamination. At the same time, maintaining its quality and characteristics represented the problem for evaluation GW at a time were faces major population growth and the urgent requirements for various development activities in light of the water war climate change and unguided use in various purposes, in addition to environmental or economic, legal and political factors that are important to take into account. Also, groundwater is a valuable resource due to its constant quality and availability, which requires minimal storage and transportation infrastructure requirements **(Ahmed, N. et al., 2014)**. GIS is a computer-based program that can collect, store, analyze, distribute, and output spatial data information. It is particularly important for presenting spatial data and baseline values, and spatial analysis results **(Bolstad, P., 2016).** Then GIS diagrams extracted from this program led to the investigation of natural and human systems and the modeling and prediction of their behaviors over time, and since that time lead a lot of research efforts in all societies to push researchers in new technology instead of by use GIS, So there has been a significant increase in the use of the evolving capability of GIS over the past three to four-decade **(Weng, Q., 2010)**. GIS can be a powerful tool for developing solutions to water resource problems, assessing water quality, determining water availability to understand the natural environment, and managing water resources at an accurate level and according to the required specifications. It is also a very powerful tool for processing, analyzing, and integrating spatial data sets. In a very broad sense, a geographic information system may mean data need identification, information acquisition, efficient management, processing, analysis, and decision-making (**Bairu, A., et al., 2013**). Successful water management needs to follow a scientifically coordinated approach to provide water management site officials with information about the decision. Therefore, to meet the needs of accumulated data for water management and water resources research, there is a great need for effective modeling techniques that have high power for long and short-term evaluation in order to be able to reach correct decisions (**Arafat, A., 2007)**. For any city, a groundwater quality map is important for determining its use; the water quality index WQI method for groundwater quality assessment is widely used worldwide due to the capability of the full expression of the water quality information. It is one of the most effective tools and important parameters for evaluating and managing groundwater quality. WQI is defined as a rating reflecting the composite influence of different water quality parameters (**Wu Jianhau, et al., 2011**).WQI is defined as a classification that reflects the combined effect of water quality indicators. WQI is calculated through the suitability of groundwater for human consumption. Its primary objective is to discuss groundwater suitability for use based on the calculated water quality index values **(Ramakrishnaiah, C., et al., 2009)**. Thus, the study was conducted to assess groundwater quality's suitability for various purposes through the Geographical Information System GIS and the Water Quality Index WQI.

2. MATERIALS AND METHODS

2.1 Study case description

Baghdad is the largest and most populous city in Iraq, with an estimated population of 8 million. Rapid and continuous population growth, accompanied by an increase in municipal, industrial, agricultural and other activities, in addition to changes in the climate, has led to changes in the quality requirements of water resources, including groundwater (**Ali, S. M., 2012)**. According to statistical studies, the city of Baghdad is confined to latitude 36º 30 - 37º 34 north and longitude 39º 20 - 49º 45 east. According to statistical studies, the percentage of urban, agricultural, and industrial areas is 72.69%, 25%, and 2.31%, respectively. These percentages show increased pollution expectations due to the increase in these percentages outside of urban planning (**Al-Jiburi, H. and Al-Basrawi, N., 2013)**. The salinity of groundwater in Baghdad varies from water (fresh to salty) with the water chloride form spread. Groundwater movement in the direction east, north, and southeast, and the transmutability factor ranges between 50-350 m^2/day in total, but the susceptibility factor decreases towards the east. The results showed that the groundwater depth for the study area ranges between 2 - 50 m (**Al–Basrawi, N., et al., 2011)**.The study area in WGS 1984- UTM-Zone 38 ° N of the Universal Transverse Mercator – UTM coordinate system structure. As shown in **Fig.1.**

2.2 Data Collection and Analysis

The research included a study of wells data, numbering 97 wells distributed randomly over the city of Baghdad are approximate coverage, collected from government departments related to groundwater studies, and these parameters include: hydrogen ion concentration pH, electrical conductivity EC, Total Dissolved Solids TDS, Calcium Ca^{2+}, Magnesium Mg^{2} ,Sodium Na +, Potassium K +, Chloride Cl -, Bicarbonate HCO_3^{-}, sulfate SO_4^{-2}, nitrate NO_3^{-}. The statistical analyses of obtained data were carried out using Microsoft offices excel and the SPSS program. Wells distribution on the study area, as shown in **Fig. 2,** data geographical for wells, as shown in **Table No.1**, and **Table No.2** Descriptive statistics for all studied wells.

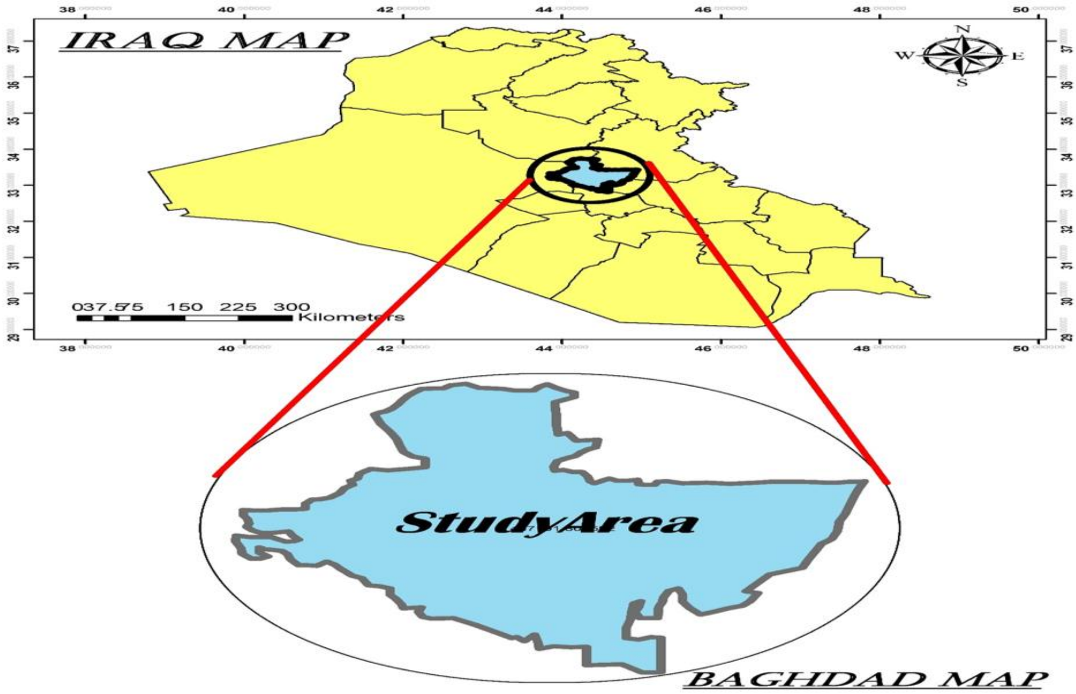

Figure 1. Location of the Study Area **(Researcher's work by GIS)**.

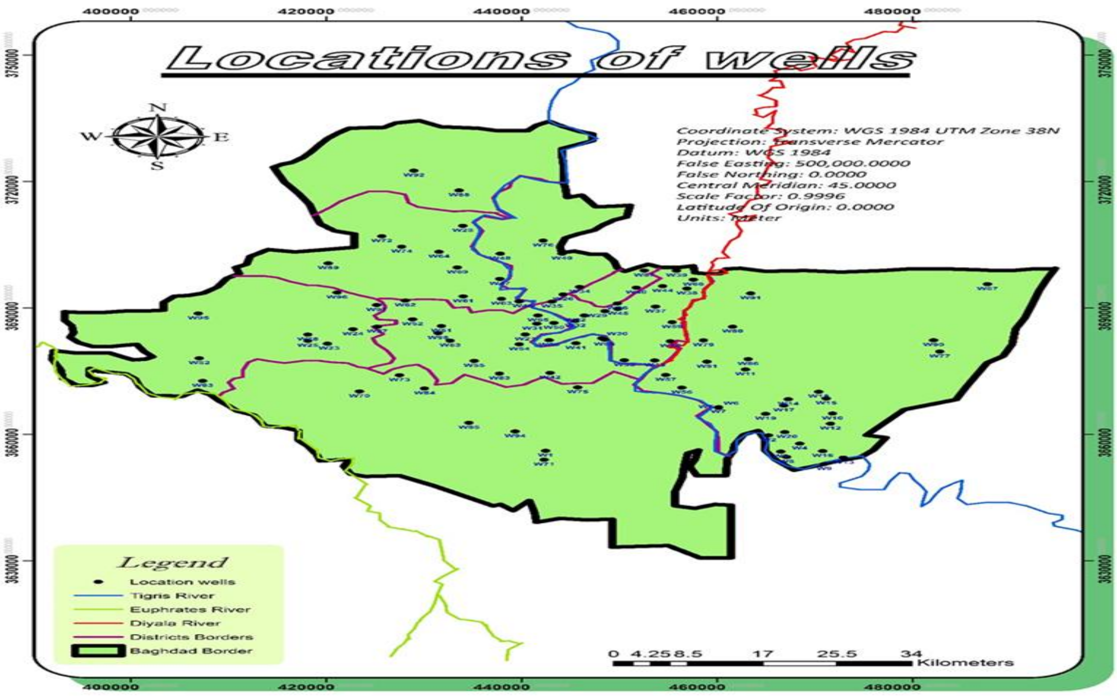

Figure 2. Wells Distribution on Study Area **(Researcher's work by GIS).**

Table 1. Wells Data Geographical for Study Area.

Wells No.	district	Longitude			Latitude		
W1	Mahmoudia	44	23	1.84	33	2	31.08
W2	Almadaeen	44	37	40.3	33	4	33
W3	Almadaeen	44	38	29.3	33	2	28.4
W4	Almadaeen	44	39	43.6	33	3	30.4
W5	Almadaeen	44	34	22.5	33	8	6.8
W6	Almadaeen	44	34	22.04	33	8	5.22
W7	Almadaeen	44	34	21.9	33	8	9.9
W8	Almadaeen	44	38	52.2	33	1	47.1
W9	Almadaeen	44	41	20.8	33	0	52.6
W10	Almadaeen	44	41	52	33	7	22
W11	Almadaeen	44	36	7	33	13	1
W12	Almadaeen	44	41	44	33	6	4
W13	Almadaeen	44	42	36	33	1	42
W14	Almadaeen	44	38	57	33	9	12
W15	Almadaeen	44	41	27	33	9	18
W16	Almadaeen	44	41	14.5	33	2	33
W17	Almadaeen	44	38	40	33	8	23
W18	Almadaeen	44	40	57	33	10	10
W19	Almadaeen	44	37	28	33	7	19
W20	Almadaeen	44	38	44.5	33	4	58.5
W21	Karkh	44	21	34.35	33	17	26.76
W22	Rusafa	44	25	27.49	33	19	54.1
W23	Abu Ghraib	44	8	33	33	16	11
W24	Karkh	44	10	13	33	18	3
W25	Abu Ghraib	44	7	15	33	16	33
W26	Adhamiya	44	24	2	33	22	36.2
W27	Karkh	44	11	49	33	18	23
W28	Kadhimiya	44	17	21	33	31	22
W29	Rusafa	44	26	49	33	20	28
W30	Karkh	44	26	37.6	33	16	58.9
W31	Karkh	44	22	20.2	33	18	50.1
W32	Rusafa	44	24	52	33	19	12.4
W33	Rusafa	44	28	7.7	33	14	9.7
W34	Adhamiya	44	25	7.2	33	23	34
W35	Rusafa	44	23	18.6	33	21	40
W36	Alssadr	44	27	37.4	33	21	27.5
W37	Rusafa	44	30	8.4	33	21	3.5

W38	Rusafa	44	32	12.2	33	23	23.4
W39	Rusafa	44	31	30.2	33	25	40.8
W40	Alssadr	44	28	51.6	33	23	29.4
W41	Karkh	44	24	55.6	33	16	20
W42	Karkh	44	23	15	33	12	31.2
W43	Rusafa	44	30	7.7	33	14	8.7
W44	Rusafa	44	30	35.7	33	23	41.2
W45	Rusafa	44	27	39.9	33	20	45.4
W46	Kadhimiya	44	21	8.6	33	21	41.3
W47	Kadhimiya	44	19	50.6	33	24	33.9
W48	Adhamiya	44	19	50.6	33	27	48.4
W49	Adhamiya	44	23	55.3	33	27	50
W50	Karkh	44	23	27.2	33	18	56.1
W51	Karkh	44	16	2.8	33	18	30
W52	Karkh	44	14	8.3	33	19	20.7
W53	Karkh	44	16	37.7	33	16	37.5
W54	Karkh	44	21	11.4	33	16	10.9
W55	Karkh	44	18	14.2	33	14	2
W56	almadaeen	44	31	56	33	10	40
W57	almadaeen	44	30	52	33	12	17
W58	Rusafa	44	31	9	33	16	37.1
W59	Rusafa	44	31	15.5	33	19	4
W60	Rusafa	44	23	9.3	33	16	43.5
W61	Kadhimiya	44	17	27	33	22	19.24
W62	Karkh	44	13	38	33	21	45.2
W63	Kadhimiya	44	19	58.5	33	22	0.9
W64	Kadhimiya	44	15	48	33	28	1.7
W65	Karkh	44	22	23.7	33	19	53.2
W66	Rusafa	44	32	37.3	33	24	31.5
W67	Alssadr	44	29	22.5	33	25	41.2
W68	Karkh	44	26	47.6	33	16	48.8
W69	Kadhimiya	44	17	1.8	33	26	1.1
W70	Mahmoudia	44	10	43	33	10	4
W71	Mahmoudia	44	22	56	33	1	22
W72	Kadhimiya	44	12	0	33	30	0
W73	Mahmoudia	44	13	20	33	12	10
W74	Kadhimiya	44	13	20	33	28	40
W75	Mahmoudia	44	25	5	33	10	40
W76	Adhamiya	44	22	40	33	29	30
W77	Almadaeen	44	48	55	33	15	20
W78	Abu Ghraib	44	7	15	33	17	20

W79	Almadaeen	44	33	20	33	16	45
W80	Almadaeen	44	35	15	33	18	30
W81	Almadaeen	44	33	35	33	14	0
W82	Abu Ghraib	44	0	7	33	14	15
W83	Karkh	44	19	55	33	12	25
W84	Mahmoudia	44	15	0	33	10	28
W85	Mahmoudia	44	17	57	33	6	5
W86	Almadaeen	44	36	17	33	14	20
W87	Almadaeen	44	52	3	33	24	0
W88	Tarmiyah	44	17	4	33	35	55
W89	Kadhimiya	44	8	30	33	26	30
W90	Almadaeen	44	48	30	33	16	48
W91	Almadaeen	44	36	25	33	22	47
W92	Tarmiyah	44	14	3	33	38	26
W93	Abu Ghraib	44	0	23	33	11	20
W94	Mahmoudia	44	21	0	33	5	0
W95	Abu Ghraib	44	9	7	33	22	45
W96	Abu Ghraib	44	11	45	33	21	10
W97	Karkh	44	15	50	33	17	35

Table 2. Descriptive Statistics for all Studied Wells.

	pHc	EC ds/m	T.D.S ppm	Ca^{2+} mg/L	Mg^{2} mg/L	$Na+$ mg/L
Mean	7.44	6976.64	5287.31	340.25	264.66	548.5
Std. Deviation	0.34	7666.98	6439.57	348.84	308.81	750.63
Minimum	7.01	780.63	661	48.1	26.6	75
Maximum	8.12	38400	39016.67	2164	1490.64	3818
	$K+$ mg/L	$CL-$ mg/L	HCO_3^- mg/L	SO_4^{-2} mg/L	NO_3^- mg/L	
Mean	63.93	1238.14	421.27	1696.72	2.32	
Std. Deviation	137.58	1866.23	512.45	1874.93	4.57	
Minimum	2	71.34	23	139.78	0.11	
Maximum	706.38	11916.83	2562	9100	30.61	

3. METHODOLOGY

The objectives of the research are achieved through adopting a data integration strategy, as the study relied on the spatial analysis approach of groundwater parameters by the GIS program to find out the feature by which the data will be integrated with WQI distribution results in the study area, to be an effective tool for planning and decision-making in relation to the protection of groundwater and managing them, the objectives of achieving the study can be generally summarized as follows:

3.1 Geographic Information Systems GIS

Many GIS techniques have been developed for spatial interpolation in various disciplines, with a number of different terms used to distinguish between them (**Al-Musawi, N. and Al-Rubaie, F., 2019)**. The method kriging has been used in this research for the spatial distribution of the determinants of groundwater data in the study area, in addition to representing or identifying appropriate places for different uses of groundwater through maps generated from the GIS after entering data to represent it through the program.

3.2 Ground Water Quality Index (GWQI)

In the research, the water quality index WQI for groundwater wells in the study area for the available data represented for all parameters, the calculation of Groundwater Quality Index GWQI was done by Weighted Arithmetic Index method **(Ramakrishnaiah, C., et al., 2009)**. This method was chosen among other methods for its accuracy and adoption within the researches. Although this method was used in studies of surface water, its application within groundwater studies has succeeded in most studies on the different conditions between surface water and groundwater.

4. RESULTS AND DISCUSSION

4.1 GW Quality Assessment

It is important to assess groundwater quality to ensure the safe and sustainable use of these resources. However, it is difficult to describe the general condition of water quality due to the spatial diversity of multiple pollutants and a wide range of indicators chemical, physical, and biological that can be measured. The chemical constituency of soil water is an indicator of its suitability for irrigation and industrial use and other water supply for human and animal consumption. Thus, the concept of water quality is not empirical, somewhat socially dependent on the desired water use **(Babiker, I. S., et al., 2007)**. By comparing the mean for parameters with the limits of the specifications shown in **Table No.3** wells under study, we see that most of the above elements are not within the permissible limits except pH, NO_3 therefore all the wells in the study area, which was mentioned, are not suitable for drinking. The mean pH, NO_3 results are 7.44, 2.32 respectively. This shows that groundwater in the study area did not exceed the permissible limits in Iraq for pH, NO_3 The standard drinking water specifications are not classified by the deterioration standards responsible for water quality. They indicated that the water samples were semi-neutral to alkaline in nature. The results showed that EC's total mean values reached 6976.64 µS / cm, indicating that most EC values were above the maximum permissible level recommended by **(IQS, 2009)** for drinking water not exceeding 1500 µS / cm. This increase indicates the relationship between EC and TDS in groundwater. High conductivity in groundwater may arise through natural weathering of some sedimentary rocks or an anthropogenic origin. High electrical conductivity was associated with higher dissolved solids, which indicated the presence of dissolved salinity, significantly in study areas that suffered high levels of TDS and EC contents. The mean of TDS was 5287.31mg /L indicating that annual values of TDS were often above the **(IQS, 2009)** permissible level for drinking water 1000 mg /L. The high concentration of dissolved solids in many wells' models was an indication that there are intense human activities that greatly affect the quality of the groundwater in the study area. The general mean for all stations was 340.25 mg/L. Most of the calcium values exceeded the permissible limits in the Iraqi specifications for drinking water not more than 150 mg /L. The data showed that there are readings within the permissible limits. High concentrations of calcium may indicate the land's geological composition in the groundwater sampling area. When some soil types have increased, the calcium content can be dissolved in the groundwater through recharge areas. The general mean of magnesium for all the stations examined was 264.66 mg /L was not within the permissible limits. The annual values were also higher than the level permitted by **(IQS, 2009)** for drinking water 100 mg /L at different locations. During the study period, this rise may be due to the nature of the lands adjacent to the well sites, which directly affect groundwater recharge places. The results of Na for the general average of all stations was 548.5 mg /L. This indicates that most of the values of sodium has exceeded the permissible limits of the Iraqi standards for drinking water not exceeding 200 mg /L and was classified within the standards responsible for the deterioration of water quality in general, significantly high sodium in the groundwater during the study period, the result of the increase in the presence of sodium salts in the feeding areas and in the rocks. The results of potassium concentrations through the data were from the general mean for all wells was 63.93 mg /L. Through the data, it is clear that most of the K values have exceeded the permissible limits according to **(IQS, 2009)** not exceeding 12 mg / L, potassium in groundwater is due to the land's nature in the feeding areas, especially in agricultural areas. The results of chlorine concentrations through the general mean for all wells were 1238.14 mg /L. Through the data, it is clear that most of the Cl values have exceeded the permissible limits according to **(IQS,2009)** not exceeding 350 mg /L, and this thus greatly affects the deterioration of the quality of groundwater chloride in groundwater is evidence of sedimentary rocks rich in chloride. It can be seen through the salty taste of groundwater, which indicates an increase in chloride salts in it. The general mean HCO_3 it 421.27 mg /L, which is higher than the maximum permissible level in drinking water 350mg/L, the high concentration of HCO_3 it comes from the action of water containing carbon dioxide on limestone, marble, and other minerals containing calcium and magnesium carbonate in the ground that can add large quantities to the groundwater. And the general mean for SO_4 was 1696.72 mg /L, which is higher than the maximum permissible level in drinking water 400 mg /L. This large increase above the permissible level may be due to man-made activities and natural resources as rocks and stones in the ground can add large quantities of sulfates to the groundwater.

Table 3. Water Iraq Quality Specification Standard.

Parameters	**Symbol**	**Unit**	**Mean**	**IOS/417, 2009**
Hydrogen Ion Concentration	**pH**	——	7.44	6.5 - 8.5
Electrical Conductivity	**EC**	µS/cm	6976.64	1500
Total Dissolved Solids	**TDS**	mg/L	5287.31	1000
Calcium	**Ca**	mg/L	340.25	150
Magnesium	**Mg**	mg/L	264.66	100

Sodium	**Na**	mg/L	548.5	200
Potassium	**K**	mg/L	63.93	12
Chloride	**Cl**	mg/L	1238.14	350
Bicarbonate	$\boldsymbol{HCO_3}$	mg/L	421.27	350
Sulfate	$\boldsymbol{SO_4}$	mg/L	1696.72	400
Nitrate	$\boldsymbol{NO_3}$	mg/L	2.32	50

4.2 GWQI

The water quality index was applied with the help of GIS technology in this study to assess the appropriateness of the groundwater quality and to calculate the water quality index WQI Ninety-seven 97 samples of groundwater were collected from the study area, as shown in **Table No.1** descriptive statistics and Iraqi drinking water standards **(IOS/417, 2009)** were taken into account for calculating the WQI as shown in **Table No. 2**. The first step to computing a water quality index is to determine specific weights of chemical parameters and their relative importance in drinking water. The highest weight was given to the nitrite coefficient NO_3 due to the importance of the role played by the water quality, more than others were. A lower weight is assigned to Na, Mg, and Ca because it is not harmful to the groundwater quality (**Ramakrishnaiah, C., et al., 2009**), and the rest of the weights as shown in **Table No.4**. In the second step, the relative weight Wi is calculated using equation number one given below:

$$Wi = \frac{wi}{\sum_{i=1}^{n} wi} \tag{1}$$

Where Wi relative weight, wi the weight of each parameter, and n is the number of parameters. The quality rating scale qi was calculated in the third step by dividing each chemical parameter concentration Ci by its respective Iraqi standards for drinking Si as shown in **Table No.4**. The result is multiplied by 100 using the following equation.

$$qi = \left[\frac{Ci}{Si} \times 100\right] \tag{2}$$

In the fourth step, Sli is calculated for each chemical parameter using the following relationship

$$Sli = Wi \times qi \tag{3}$$

Finally, the Water Quality Index WQI was calculated using the following equation:

$$WQI = \sum Sli \tag{4}$$

Table 4. The calculated relative weight Wi values of each parameter.

Parameters	Sl	Weight wi	Relative weight Wi
Hydrogen Ion Concentration	6.5	4	0.125
Total Dissolved Solids	1000	4	0.125
Calcium	150	2	0.0625
Magnesium	100	2	0.0625
Sodium	200	2	0.0625
Potassium	12	3	0.09375
Chloride	350	3	0.09375
Bicarbonate	350	3	0.09375
Sulfate	400	4	0.125
Nitrate	50	5	0.15625
$\sum$		**32**	**1**

The water quality index WQI values were classified into five types **(Ramakrishnaiah, C., et al., 2009)**, as shown in **Table 5.** Comparing the results of the calculated water quality index classification shows that 3 % of water samples in class I (type of water excellent), and shows that 30% of the water samples fall in the second category II, which represents the quality of good water and 33% of the water available well falls under the third category III, representing of poor water quality, 12% percent of the water sample falls in category IV which indicates that the water quality is very poor and 22% percent of water samples fall in category V indicating unsuitable water for drinking purposes.

The WQI is a valuable assessment of the state of total water quality in a single term and helps choose the appropriate treatment method to meet the requirements. However, WQI portrays the combined effect of water quality standards and their variations and conveys information on water quality standards to the user and decision-makers. The WQI aims to give a single value to the quality of groundwater and reduce the number of indicators to a greater extent in easy expression leading to a possible interpretation of the data for monitoring water quality standards. Besides, this is an effort to review important groundwater indicators used in the assessment, and it also provides information on the formation of mathematical indicators and figures **(Tyagi, S., et al., 2013).** It can also be summed up by showing the variation between wells for water quality index WQI in the study area through **Fig. 14, Fig. 15,** and **Fig. 16**. Therefore, it is necessary for the researchers to have a complete perception of the distribution of the water quality index in the study area. And this is done through Integration spatial analysis by geographic information systems GIS program with of the data extracted through the calculations of WQI, as shown in **Fig. 17** where the distribution of water quality areas can be used in studies as well as uses the different groundwater that gives an idea of the area to be invested groundwater in it.

Table 5. Result percentage of studied water samples in the study area based on WQI value.

WQI Value	Class	Water quality	WQI for Wells	Well Number	% studied sample
< 50	I	Excellent	43,27,42	50 , 85 , 94	3 %
50-100	II	Good	68,69,100,75,88,72, 69,67,85,94,87,53 ,74,78,93,80,87,52, 60,78,62,100,66,67, 69,90,67,99,64	8 , 11, 12 , 14 , 20 , 23 ,24, 25, 26 ,29 ,31, 33 ,34,37,38,39,40,42 ,45,51,59, 61 , 62 , 63 , 64 , 65 , 66 , 82 , 93	30 %
100-200	III	Poor	143,115,122,102,131, 152,147,176,102,119, 150,123,115,126,105, 132,117,108,183,161, 165,183,111,165,175, 105,181,121,197,189, 197,150	1 , 2 , 3 , 5 , 7 , 10 , 16 , 27 , 28 , 30 , 32 , 35 , 36 , 41 , 49 , 52 , 55 ,56 , 57 , 58 , 60 , 67 , 68, 69 , 70 , 75 , 80 , 83 , 87, 89 , 96 , 97	33 %
200-300	IV	Very Poor	286,299,290,298,248, 201,250,249,284,288, 295,218	6 , 9 , 17 , 18 , 48 , 54 , 73 , 78 , 79 , 88 , 92 , 95	12 %
>300	V	Un suitable	309,1573,972,1241, 1166,850,331,307,643, 467,464,678, 314, 666, 877,1136,401,515,316, 815,534	4 , 13 , 15 , 19 , 21 , 22 , 43 , 44 , 46 , 47 , 53 , 71 , 72 , 74 , 76 , 77 , 81 , 84 , 86 , 90 , 91 ,	22 %

4.3 GIS

The GIS program is considered an ideal display interface in managing and auditing water resources data, including groundwater, as it has been used in the research by entering groundwater data available for 97 wells sites in the study area, organizing and analyzing and display the program, through maps that are displayed with high accuracy showing the spatial distribution. After obtaining the final information based on spatial analysis through the program, GIS is done taking the appropriate decision regarding it that by choosing the right place for drilling wells to obtain the groundwater necessary for the various industrial, agricultural, constructional and other thus the successful management of this important resource and to be use in the right place according to the global and local specifications and determinants. (**Jha, M., et al., 2007**)

Where it was done and through the results of examining water models for the wells under study by the competent departments, which were within the boundaries of the city of Baghdad and as shown in the statistical description in **Table No.2** and distribution results appeared after entering these data into the program, as it was noticed through **Fig. 3.** The value of pH ranges between 8.6 - 8.5 in most wells in the study area and its distribution within the permitted Iraqi specifications, as shown in **Table No.3**. From **Fig. 4,** it is shown that the value of EC in the study area was the lowest value 2600 mg/L, which is a result outside the permissible limits, and it is also seen from **Fig. 5** that the most readings TDS at the study area ranges between 1200-6000 mg/L and the rest of the sites ranges between 6000-25000 mg/L and therefore its value is outside the limits. For the permissible standard, it is also clear to us that the value of Ca, Na as shown in **Fig. 6** and **Fig. 8** there are few places where readings are within the limits of the Iraqi standard and the rest of the distribution, which represents most of the study area, was not within the standard. Through the results of the GIS program drawing with values of Mg, K as shown **Fig. 7** and **Fig. 9,** it becomes clear to us that most of the study area have high values less than the required levels in addition to SO_4 as shown in **Fig. 12**, and also with a value see CL as shown in **Fig. 10** it is noticed that most of its results in the study area are less than the Iraqi specification, which is 350 mg/L, and the program map resulting from HCO_3 data, as shown in Fig. 11, indicating that the western regions up to the north and part of the central regions For the study area is within the limits of the Iraqi standard and its values increase in other regions, and finally the area of data, distribution NO_3 as shown in **Fig. 13,** clarifies that the whole study area is within the standard. Generally, soluble ions and salts are the main components of groundwater. Calcium, magnesium, sodium, bicarbonate, sulfate, and chloride are major ions in drinking water. Potassium, carbonate, and nitrate are beneficial, but it may cause severe problems for humans when increased.

From the above, a complete and clear perception of the values of groundwater data for the wells of the study area can be seen, through which and through the GIS program, it is easier for researchers to have a lot of effort time and research in the event that there are areas where data and information are not available to them and the difficulty of obtaining it due to the lack of time and effort.

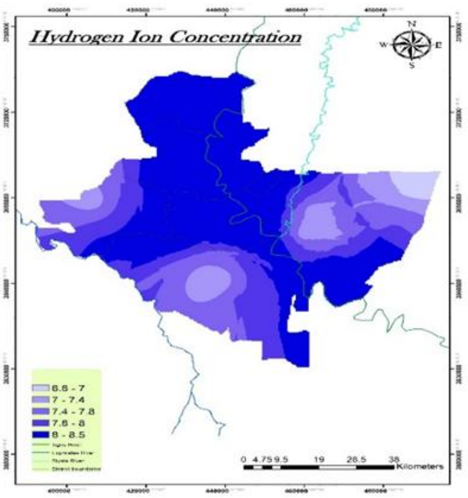

Figure 3. Distribution PH.

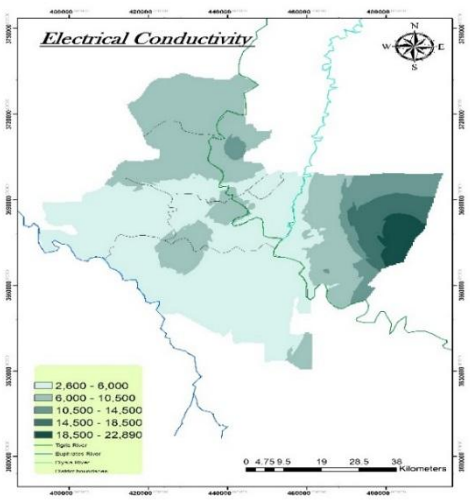

Figure 4. Distribution EC- µS/cm.

(Researcher's work by GIS)

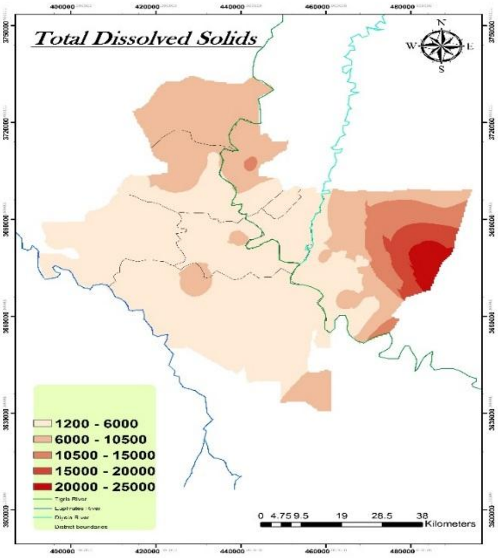

Figure 5. Distribution TDS- mg/L.

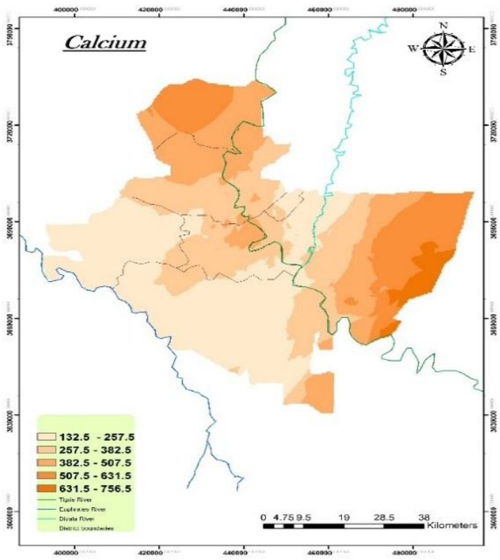

Figure 6. Distribution Ca- mg/L.

(Researcher's work by GIS).

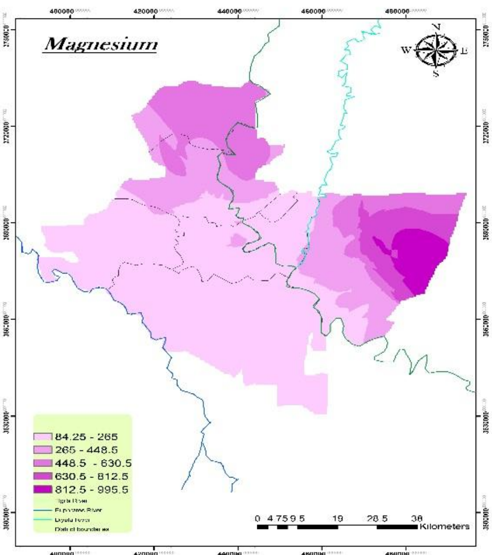

Figure 7. Distribution Mg- mg/L.

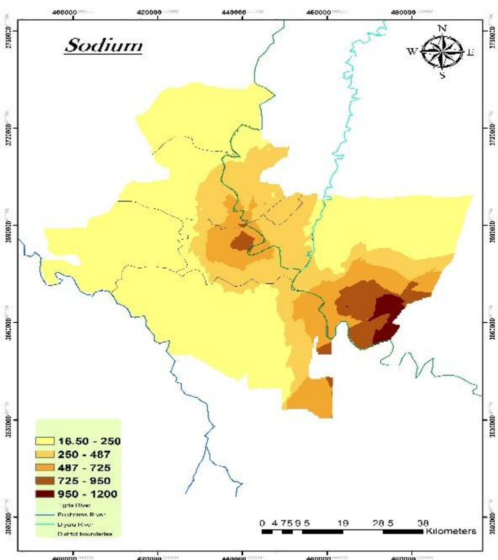

Figure 8. Distribution Na- mg/L.

(Researcher's work by GIS)

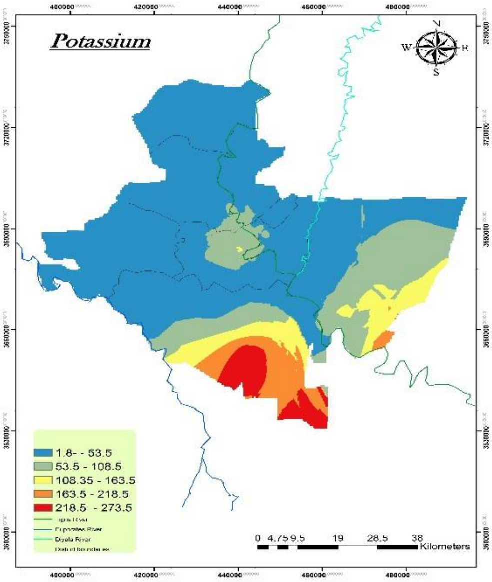

Figure 9. Distribution K- mg/L.

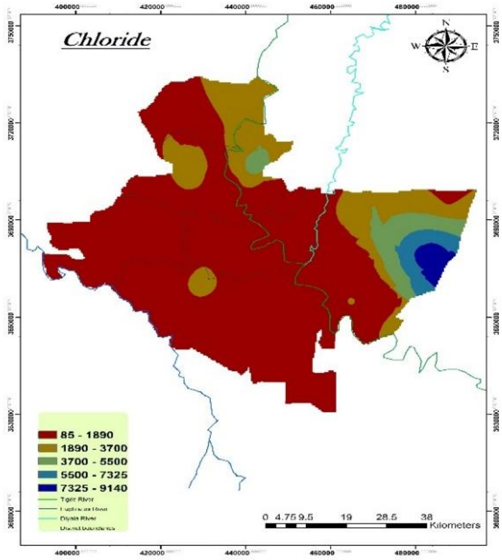

Figure 10. Distribution CL- mg/L.

(Researcher's work by GIS)

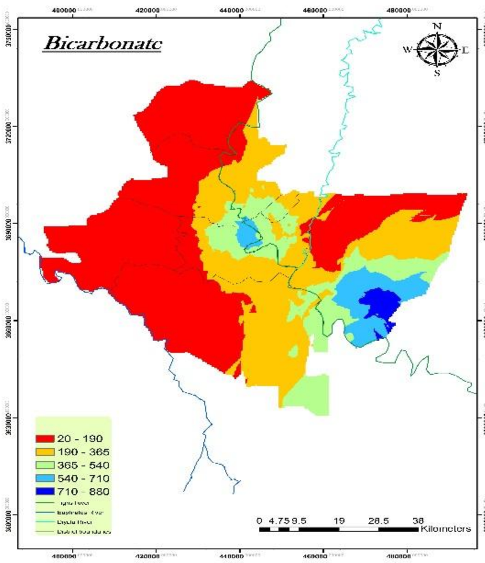

Figure 11. Distribution HCO_3 mg/L.

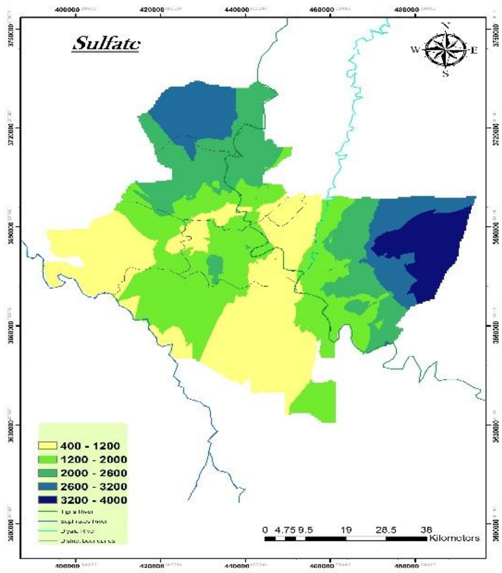

Figure 12. Distribution SO_4 mg/L.

(Researcher's work by GIS)

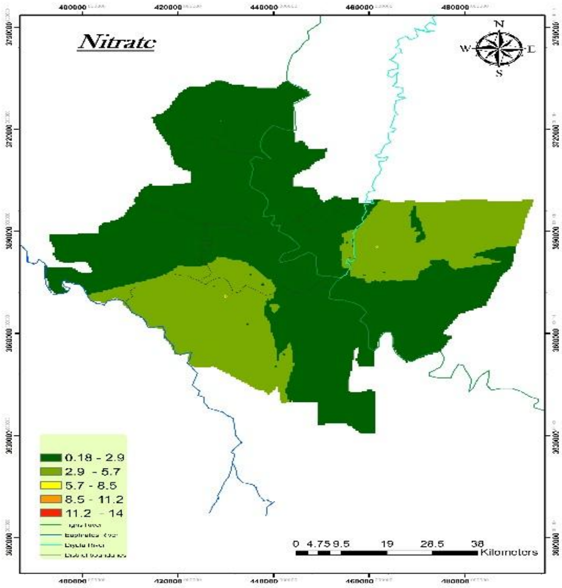

Figure 13. Distribution NO_3 mg/L.

(Researcher's work by GIS)

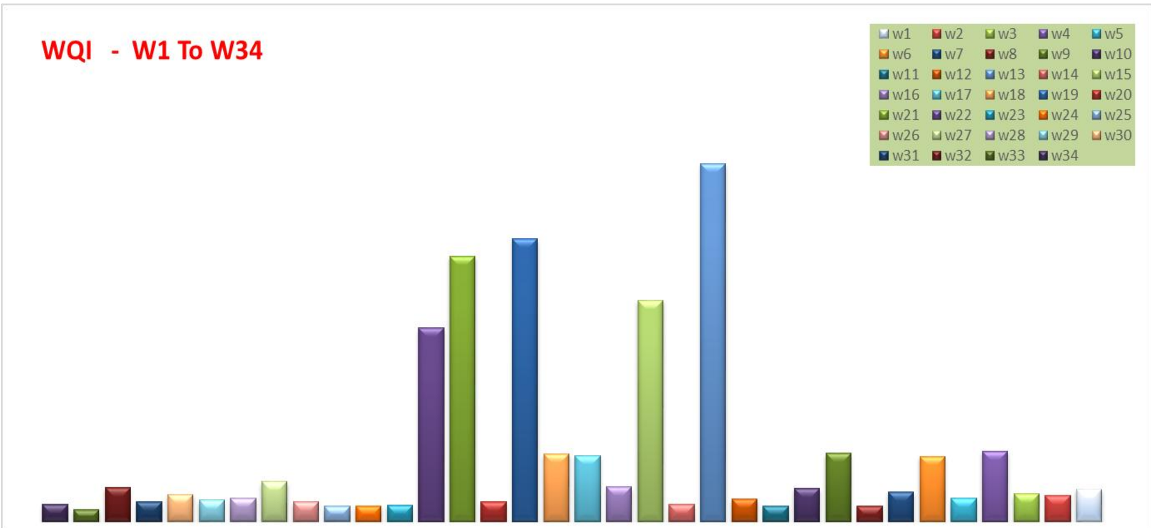

Figure 14. Showing the amount of variation in the WQI between wells for W1 to W34.

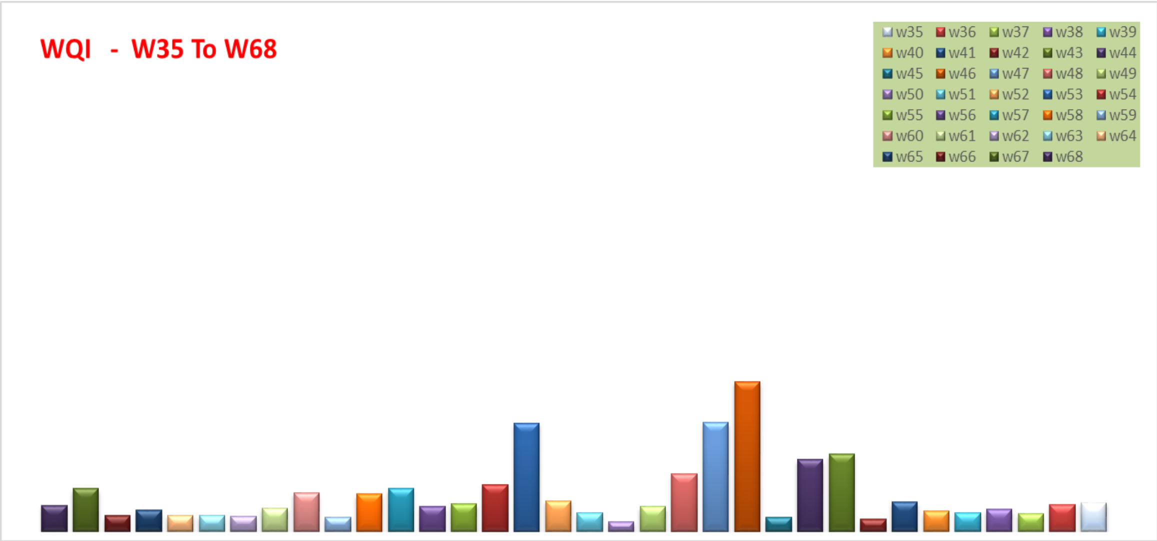

Figure 15. Showing the amount of variation in the WQI between wells for W35 to W68.

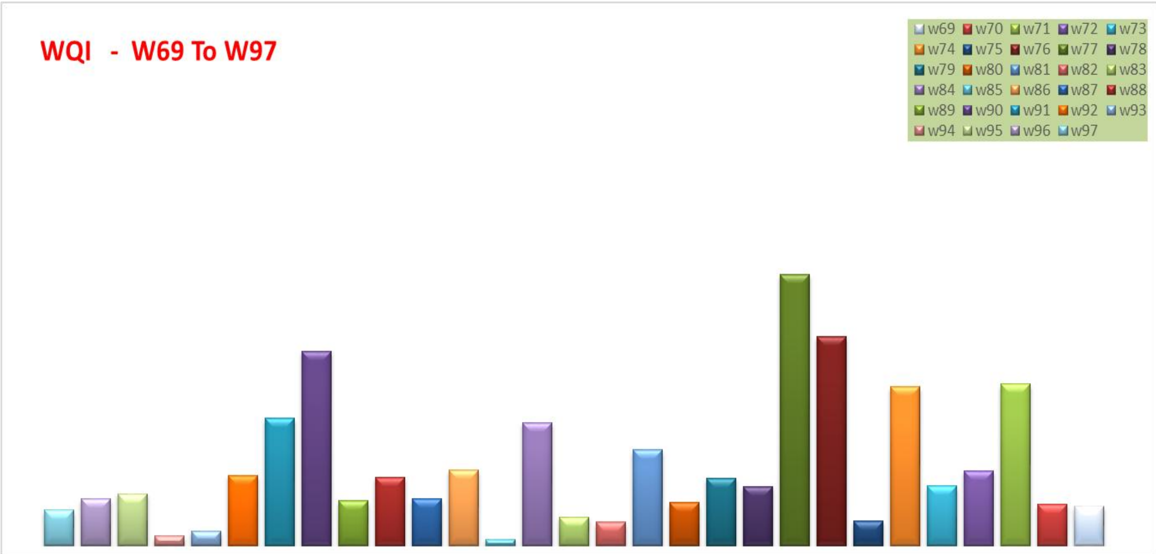

Figure 16. Showing the amount of variation in the WQI between wells for W69 to W97.

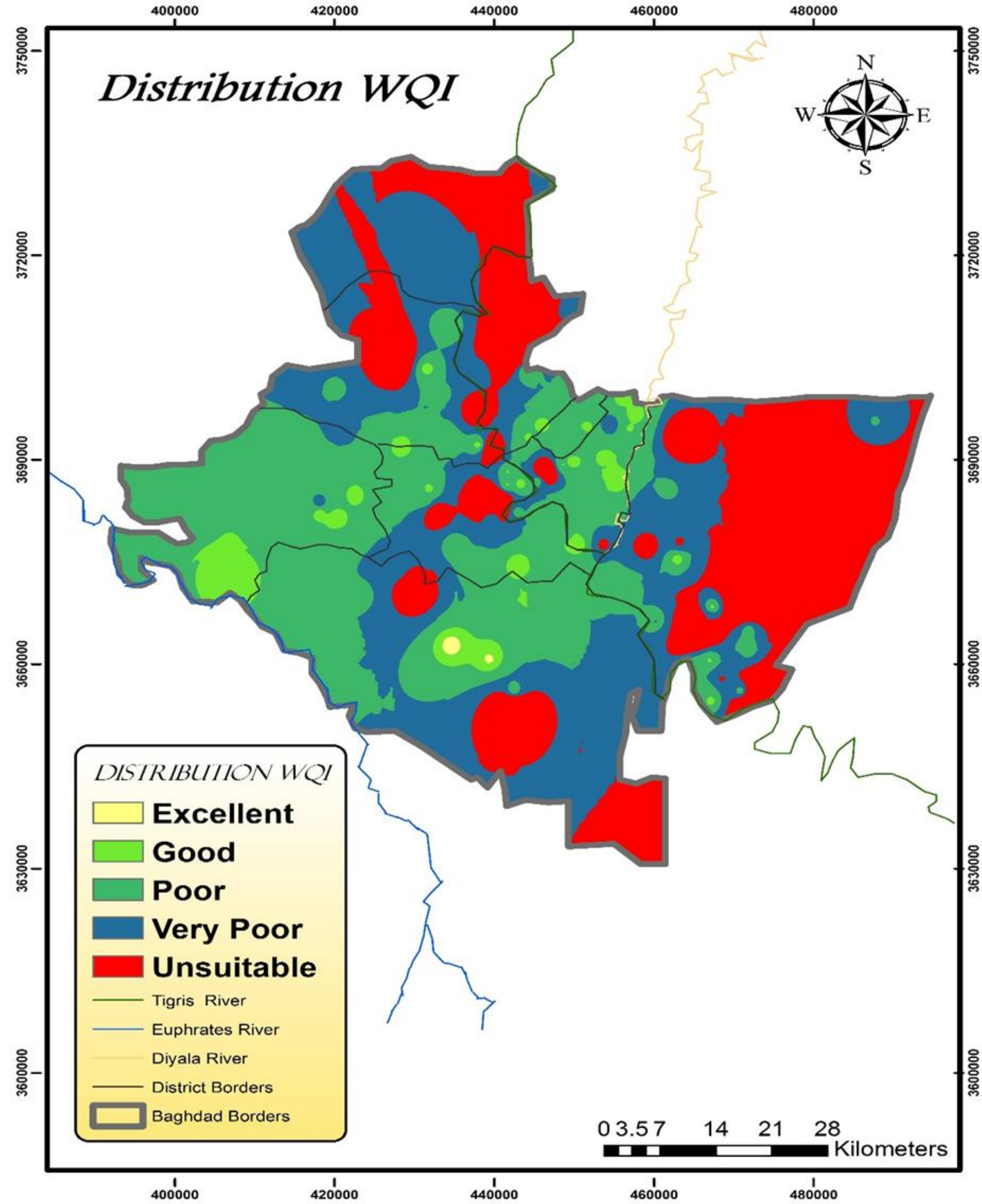

Figure 17. Spatial Analysis for WQI in Study Area **(Researcher's work by GIS).**

5. CONCLUSIONS

1- Spatial analysis of groundwater quality has been carried out through GIS and WQI techniques that can provide highly useful and effective tools for summarizing monitoring data for decision-makers to understand better the state of groundwater quality and the opportunity for its better use in the future.
2- The differences between WQI index values for wells in Baghdad city due to water leakage from sewage networks and partial treatment of sewage discharge in the Tigris River.
3- The spatial distribution results comparing with (**IQS, 2009)** showed that the groundwater water quality in most of the study area is not suitable for drinking, but use for other as industrial, agricultural and other.
4- The WQI results maps in the study area confirm that the groundwater in the study area suitable for drinking purposes after treatment in the western regions and part of the central and eastern regions towards the southwest, where the ground level rise and the level of deep groundwater. The north and southeast direction towards the south is the opposite due to the low ground level and shallow groundwater level. In general, the study area's groundwater needs a certain degree of treatment before consumption and must be protected from pollution.
5- In general, the main water parameters EC, TDS, Ca, Mg, K, Cl, Na, HCO_3 and SO_4 not within the limits of the specification (**IQS, 2009)**. On the other hand, concentrations were PH, NO_3 within the limits
6- It is possible, through the maps of spatial analysis by GIS of the physical and chemical parameters of groundwater, to be adopted as a strategy in the event of digging new wells and to be the basis for the management and planning of the drilling process to obtain near-identical results for the old drilled wells as they save time, effort and cost through that to obtain high-accuracy results.

REFERENCES

- Ahmed, N., Taylor, S. W., and Sheng, Z. (Eds.), 2014, July. Hydraulics of Wells: Design, Construction, Testing, and Maintenance of Water Well Systems. American Society of Civil Engineers.

- Ali, S. M., 2012. Hydrogeological environmental assessment of Baghdad area. Department of Geology, College of Science, University of Baghdad, Baghdad, Iraq. p. 6.

- Al–Basrawi, N. H., Awad, J. H., and Hussain, T. A., 2015. Evaluation of the Ground Water in Baghdad Governorate/Iraq. Iraqi Journal of Science, 56(2C), 1708-1718.

- Al-Jiburi, H.K., and Al-Basrawi, N.H., 2013. Hydrogeological and Hydrochemical Study of Baghdad Quadrangle. GEOSURV, int. rep. no. [3477].

- Al-Musawi, N. O., and Al-Rubaie, F. M., 2019. The Effect of Diyala River Water Quality on the Quality of Tigris River Water using GIS Mapping. *Journal of Engineering*, *25*(10), 71-87.

- Arafat, A. R., 2007. Integrated Water Resources Planning for A water-Stressed Basin in Palestine (Doctoral dissertation).

- Bairu , A., Tadesse, N., and Amare, S., 2013. Use of geographic information system and water quality index to assess suitability of groundwater quality for drinking purposes in Hewane areas, Tigray, Northern Ethiopia. Ethiopian Journal of Environmental Studies and Management, 6(2), 110-123.

- Babiker, I. S., Mohamed, M. A., and Hiyama, T., 2007. Assessing groundwater quality using GIS. Water Resources Management, 21(4), 699-715.

- Bolstad, P., 2016. GIS fundamentals. A first text on geographic information systems. Eider (Press Minnesota).

- Jha, M. K., Chowdhury, A., Chowdary, V. M., and Peiffer, S., 2007. Groundwater management and development by integrated remote sensing and geographic information systems: prospects and constraints. Water Resources Management, 21(2), 427-467.

- IQS/417, 2009. Iraqi Criteria and Standards for Drinking Water Limits. Second Update for Chemical and Physical Limits, ICS: 13.060.20, Central Organization for Quality Control and Standardization, Council of Ministers, Republic of Iraq.

- Ramakrishnaiah, C. R., Sadashivaiah, C., and Ranganna, G., 2009. Assessment of water quality index for the groundwater in Tumkur Taluk, Karnataka State, India. E-Journal of Chemistry, 6.

- Tyagi, S., Sharma, B., Singh, P., and Dobhal, R., 2013. Water quality assessment in terms of water quality index. American Journal of water resources, 1(3), 34-38.

- Weng, Q., 2010. Remote sensing and GIS integration: theories, methods, and applications. New York: McGraw-Hill.

- Wu Jianhau, Li Peiyue, and Qian Hui., 2011. Groundwater Quality in Jingyuan County, a Semi-Humid Area in Northwest China. E-Journal of Chemistry, http://www.e-journals.net, 8(2), 787-793, ISSN: 0973-4945.